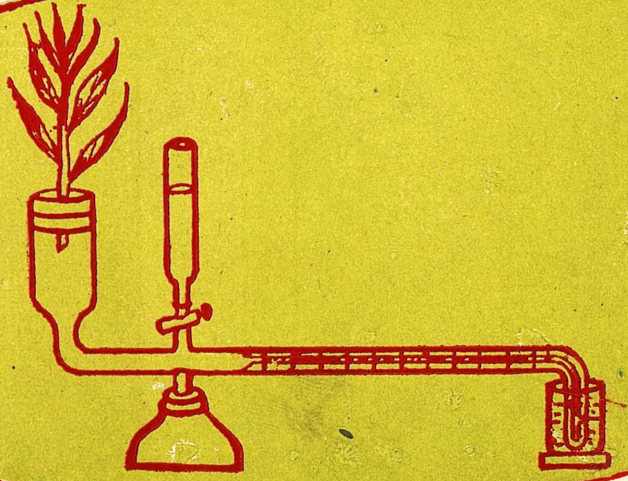
BOTANY

HIGHER SECONDARY
FIRST YEAR



TAMILNADU TEXTBOOK SOCIETY

BOTANY

Higher Secondary—First Year

TAMILNADU TEXTBOOK SOCIETY
MADRAS

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CONTENTS

		Page
1.	Introduction	1
2.	Root System	7
3.	The Shoot System	
	A. Stem	46
	B. The Leaf	85
4.	Inflorescence	128
5.	The Flower	138
6.	Fruits and Seeds	200
7.	Vegetative Propagation	222
8.	Growth and Movements	227
	ANNEXURE	
	—Anatomy : Figures	

CHAPTER I.

INTRODUCTION

Botany is the science of plants. The word Botany is derived from the Greek word *botane*, meaning herb. Botany has several branches dealing with the different aspects of plant life.

Significance of plants in relation to Agriculture

The cultivation of crop plants started on the day when ancient man collected and stored the seeds of certain plants only for sowing in the next season. Since then he has been discovering a variety of food crops namely cereals, millets, tubers, fruits, nuts and seeds. He has also learnt different methods of cultivation. He has improved the soil by applying different types of manures. He has also improved and selected better seeds for cultivation in the next season. He has also learnt the particular season in which he has to sow and harvest his crops. He has gradually learnt the particular requirements of crop plants such as moisture, manure etc. He has also learnt to develop better and improved agricultural implements. With all these man has become a good agriculturist. Several research workers are engaged in plant breeding methods, in finding out disease resistant, drought resistant varieties which can be sown in all seasons. They try to evolve varieties which can give better and quicker yield. The diseases found in plants are treated with many chemicals. Weeds are controlled so that the crops can grow well and give better yield.

Significance of plants in relation to Horticulture

Man was not satisfied with growing cereals, millets and pulses only. He was in pursuit of good fruits. He has grown a few plants for beautiful flowers. He has begun to develop small gardens around him just to appreciate the beauty of nature. He has collected the plants with beautiful flowers

from far and near and cultivated them. In course of time he has improved the varieties also. He has learnt the different methods of propagating plants like cutting so as to get improved varieties and thus the science of horticulture developed.

Significance of plants in relation to Forestry

All the useful plants were once found only in forests. Forests are the real source of wealth to human beings. Forests bring rain to the country thereby providing water to human beings, animals and plants. The trees found in forests provide valuable timbers which have definite place in the history of civilisation. Besides timber, cork, rubber, resins, lac, dyes and many other useful products are also obtained from the forest trees.

Significance of plants in relation to Industry

Plants provide basic raw materials for the industries. Unless cotton is cultivated there will not be many textile industries. There are also several natural fibres such as hemp (*Cannabis. sativa*) and flax (*Linium usitatissimum*). Jute extracted from *Corchorus capsularis* and *Corchorus olitorius* forms the important raw material for the jute industry.

Forest trees provide the basis for wood-based industries like sawing, sizing of the wood, and preparation of wood pulp which is very essential for the manufacture of rayan and paper. Industrial preparation of plywood, veneer is largely dependent upon the supply of wood.

Industrial preparation of paints, oils, varnishes and turpentine are mainly dependent upon the oils, resins and gums extracted from plants.

Oil extracted from many oil yielding plants feed the perfumery, cosmetic and soap manufacturing industries.

Industries also provide the surplus of materials which are exported to foreign countries, thereby earning valuable foreign exchange. Plant products obtained from Coffee, Tea, Cashewnut, Pepper and Cardamom are exported to foreign countries

Significance of plants in relation to Medicine

Plants also give us medicines to keep the body fit and free from diseases. All the systems of medicines such as Ayurvedic, Siddha and Yunani are solely dependent upon plants for their medicines. Allopathic system of medicines has now turned towards plants like *Rauwolfia serpentina*, *Vinca rosea* etc. so as to get valuable drugs not available from any other source. In addition to the higher plants, the lower group of plants like fungi and actinomycetes also provide us with valuable medicines like Penicillin, Streptomycin, Aureomycin etc.

Botany in relation to Human welfare

1. Food

Plants provide the necessary food materials to the human beings and animals. Without food man cannot live. Green plants possess the wonderful substance namely the chloroplasts by which they can prepare their own food out of simpler raw materials such as carbon dioxide water and sunlight. Plants store their reserve food materials in their storage organs which are exploited by man. All the cereals, pulses, oils, fruits, seeds and vegetables are obtained only from plants.

2. Clothing

Next to food come clothes. Clothes are chiefly made from cotton, which is woven into a variety of colourful fabrics. In addition to this, there are other types of fibres which are made use of in the preparation of ropes, nets, brushes, carpets etc.

3. Houses

Man requires a comfortable place to live in. Whether he is a rich person living in a palace or a poor person living in a hut, everyone requires the help of plant materials for building houses. Doors, windows, furniture and others like boxes are all made from the wood obtained from plants.

4. Medicines

The plants not only fulfil the basic requirements of life by providing food, shelter and clothing but also provide the necessary medicines to man. While the indigienous systems of medicines like Ayurvedic and Siddha systems solely depend upon plants for their medicines, Allopathic medicines are also largely prepared from plants like belladona from *Atropa belladona*, reserpine from *Rauwolfia serpentina*, Quinine from *Cinchona officinalis* and digitalin from *Digitalis purpurea*.

5. Fats and oils

These are hydrocarbons which remain in solid form at ordinary temperature. These are stored up in seeds and fruits like *Arachis hypogea* (Groundnut oil), *Sesamum indicum* (sesame oil) and *Ricinus communis* (castor oil) *Cocos nucifera* (coconut oil) and *Elaeis guieensis* (oil palm). The high energy content of fats favour them for human consumption. In addition to this, these oils are largely used in the manufacture of soaps, candles, plastics, linoleum etc.

6. Essential oils

These are the aromatic volatile oils formed in the special cells or glands of plants. Man uses these oils in the preparation of cosmetics, perfumes, creams and powders. e.g. *Attar* from *Rosa damascena*, cananga oil from *Cananga odorata*, geranium oil from *Pelargonium fragrans*, sandal wood oil from *Santallum album*, lemon grass oil from *Cymbopogon citratus*.

7. Spices

Man is not satisfied with the cereals and pulses alone for his food. He wants certain spices which give special taste and flavour to his dishes. Such spices are obtained from plants like *Cinnamomum zeylanicum* (*cinnamon*), *Elettaria cardamomum* (*cardamom*), *Piper nigrum* (*black pepper*) *and Eugenia caryophyllata* (*cloves*).

8. Beverages

In addition to all these a few palatable and refreshing drinks like coffee, tea, and cocoa are obtainted from *Coffea*

arabica, *Thea chinensis* and *Theobroma cocoa* respectively. These are known as non-alcoholic beverages which are used by 80% of the world's population.

9. Rubber

Natural rubber is prepared, from the latex of *Hevea brasiliensis* from which many industrial and commercial products are made.

10. Narcotics

Human beings smoke or chew various plant products for pleasure or even for narcotic effect.

Plants bring showers, remove atmospheric pollution, and they also provide food, shelter, medicine, beverages, cosmetics, perfumes and many more useful things to human beings. The beauty and glory of Nature has been weaved into volumes of poetry by ancient and modern poets in all languages.

Botany and its prospects

The science of plants deals with their external and internal structures (Morphology and Anatomy), their functions such as nutrition, growth, movements and reproduction (Physiology), their adaptations to the varying conditions of environment (Ecology), relationships and classification (Taxonomy), the laws of evolution from simpler to more complex ones (Evolution), the laws of heredity (Genetics), their economic uses (Economic Botany), and lastly the methods of improvement of crop plants (Plant breeding).

Due to the population explosion, many pessimistic futurlogists are painting a sorrowful picture about the food problem of human beings in 2000 A.D. But men and especially the scientists are ingenious enough to find out ways and methods to increase food production on land, water and even in space. By knowing the intricate mechanism of photosynthesis, the efficiency of food production of plants can be increased many times. Even an unicellular alga like *Chlorella* can be used as

food. Improvement of crops can be done to produce high yielding disease-resistant varieties. Due to single cell culture methods, instead of crossing two different plants, two cells belonging to the latter can be crossed and a new variety can be produced from them by culture method. Plant breeding methods can be perfected and improved in such a manner that we cancultivate the desired plants with desired characters in the chosen season.

The threatening menace of pollution of water and air need not worry the intelligent human being, for he can solve it by growing plants around him.

There is much work to be done in the exploitation of food, medicines and the like from the lower groups of plants such as alga and the fungi.

CHAPTER 2

ROOT SYSTEM

PARTS OF A PLANT

When a plant is carefully removed from the soil, two important parts are observed. The green portion of the plant above the soil is called the ***shoot system.*** The portion of the plant below the level of the soil is called the ***root system.*** The shoot system and root system are continuous.

Root system: The root system of the plant is usually brownish in colour. In continuation of the shoot, there is a large root which grows straight into the soil, called the ***main root*** or ***primary root.*** It may be sparingly or profusely branched. The primary root with its branches constitutes the ***tap root system.***

Shoot system: This is the portion of the plant found above the soil. It consists of a main stem with ***branches, leaves, buds, flowers*** and ***fruits.*** The portion of the stem with one or more leaves attached is called ***a node.*** There are several such nodes in a stem. The distance between any two adjacent nodes is known as the ***internode.*** The upper angle formed between the stem and leaf is called the ***axil*** of the leaf. If there is a bud in the axil, it is known as the ***axillary bud.*** The bud that is found at the apex of the plant is called the ***terminal bud.***

The root system and the shoot system without flowers and fruits together constitute the ***vegetative body*** of the plant because they do not take part in sexual reproduction.

When the plant reaches a certain stage of development it produces flowers, fruits and seeds. The seeds germinate to

give rise to new plants and thus serve the function of reproduction of the plant. Since the flowers, fruits and seeds are

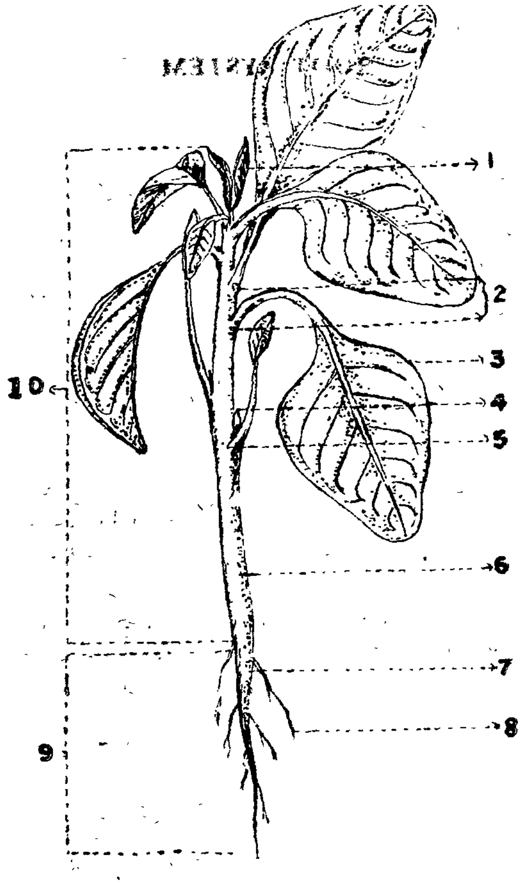

FIG. 2.1 Parts of a plant
1. Terminal bud 2. Internode 3. Leaf 4. Axillary bud 5. Node 6. Stem 7. Primary root 8. Lateral root 9. Root system 10. Shoot system

involved in reproduction they are included in *reproductive system*, (Fig. 2.1).

General characteristic features of root:

(1) The main root grows towards the centre of the earth and therefore is said to be *positively geotropic*. The branch roots grow in any direction under the soil.

(2) The lateral roots arise *endogeneously*.

(3) There are no nodes and internodes.

(4) Leaves and buds are absent in the roots.

(5) Root hairs and root caps are present in the roots.

(6) The underground roots are not green in colour.

Kinds of root system

1. *Tap root system:* During the germination of the seed the radicle grows and develops into the *Primary* or *tap root* which gives off secondary and *tertiary roots* in turn. While the primary or taproot grows vertically downwards into the soil, the secondary roots grow obliquely at an angle to the primary root. The entire collection of such roots is called *normal root system* or *tap root system*, which is characteristic of dicotyledonous plants like Bean, Castor, etc. (Fig. 2.2).

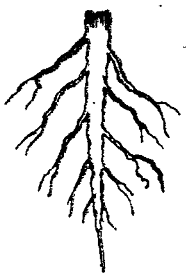

FIG. 2.2 Taproot system

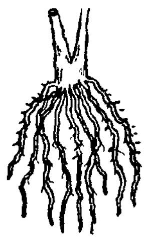

FIG. 2.3 Fibrous root system

2. *Fibrous root system:* During the germination of the seed, the radicle develops into the primary root which is short lived. Instead of this, several roots arise from the stem base which

appear like fibres. So this type of root system is described as the *fibrous root system.* This is characteristic of *monocotyledonous plants* like paddy, grasses etc. (Fig. 2.3).

Normal and adventitious root systems

The tap root system with its primary root and several lateral roots is called the normal root system.

When the roots arise from some other parts of the plant such as stem or leaf other than radicle they are called *adventitious root system.* Fibrous root system of monocotyledonous plants is an example for adventitious root system. Adventitious root system is also seen in a few dicotyledonous plants.

Regions of the root

In both normal and adventitious root systems, four distinct *regions* or *zones* may be observed. The regions of a root are best studied from any seedling like that of mustard or pea. (Fig. 2.4)

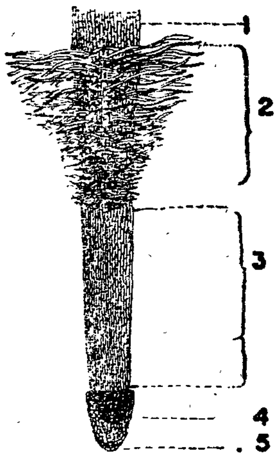

FIG. 2.4 Regions of the Root
1. Region of cell maturation
2. Root hair region
3. Region of cell elongation
4. Region of cell division
5. Root cap

1. *The root cap region.* The tip of the root is protected by a fine cap like structure known as the *root cap.* This root cap protects the delicate root tip while it is growing down into the soil. Due to its friction with soil particles, the outer part of the root cap wears out and it is being constantly replaced by new cells. While most plants show such a *simple root cap* there are some which show some variation. In *Pandanus*, the root cap is multi layered and is called *multiple root cap.*

In free floating water plants, like *Lemna* and *Pistia*, they appear like loose pockets and are called *root pockets.*

2. *The region of growth:* Just behind the root cap there is a very short region of growth which may be sub-divided into *region of cell division* and *region of cell elongation.*

(*a*) *Region of cell division:* This is the growing apex of the root lying within and a little behind the root cap and it extends to a few millimetres. The cells of this region are comparatively small, thin walled containing dense cytoplasm and large nuclei. These cells divide repeatedly and are known as *meristematic cells.*

(*b*) *Region of cell elongation:* The newly divided cells undergo elongation and enlargement and are responsible for growth in length of the root.

3. *Root hair region:* Just above the region of cell elongation, the root produces a cluster of very fine delicate thread like structures called *root hairs.* These are the unicellular extensions of the epidermal cells of the root. Root hairs are useful to absorb water containing mineral salts from the soil. These are short lived and are constantly renewed.

4. *Region of maturation:* The region behind the root hairs is known as the region of maturation or the *permanent region.*

Functions of the root

1. *Fixation or anchorage:* Plants are fixed to the soil by their extensively branched root system.

2. *Absorption:* The root system is surrounded by soil particles with thin films of water containing mineral salts. The roots absorb solutions.

3. *Conduction:* Roots conduct solution absorbed by the root hairs to other parts of the plant.

Modification of roots

Besides the above mentioned normal functions the roots may carry on certain special functions. In such cases the form of the root is also changed and it is said to have undergone modification.

1. *Tuberous roots* : In some plants, the roots serve as store-houses of food materials. Therefore they have a swollen and fleshy appearance. Such roots are called *tuberous roots* or *root tubers*.

A. Tap root or hypocotyl modification

Some plants store their food materials in their tap roots or hypocotyl and thus become swollen. Such swollen roots are named as follows according to the shape.

Fig. 2.5
Conical

Fig. 2.6
Fusiform

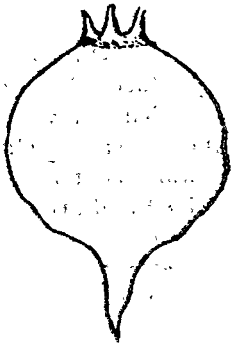

Fig. 2.7
Napiform

(i) *Conical* When the root is broad at the top and gradually tapers downwards like a cone, it is said to be conical e.g., carrot (*Daucus carota*). (Fig. 2.5)

(ii) *Fusiform* When the root is broad in the middle and tapering towards both ends like a spindle, it is said to be fusiform, e.g. radish (*Raphanus sativus*). (Fig. 2.6)

(iii) *Napiform* When the root is considerably swollen at the upper part and abruptly tapering towards the lower end, it is called napiform, e.g. beetroot, turnip. (Fig. 2.7)

B. Adventitious root modifications

(*a*) In sweet-potato adventitious roots become swollen and form the edible root tubers. It is not having a definite shape of its own (Fig. 2.8).

(*b*) ***Fasciculated Roots:*** When a number of adventitious root tubers are found in a cluster at the base of the stem they are said to be fasciculated as in *Dahlia*, *Ruellia tuberosa and Asparagus mosus* (Fig. 2.9).

Fig. 2.8
Adventitious roots tuber

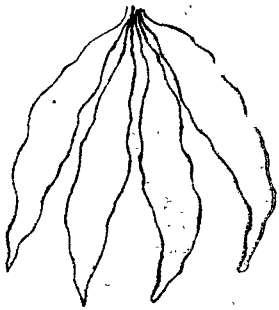

Fig. 2.9
Fasciculated roots

(*c*) ***Nodulose***. When the tips of the roots are swollen they are described as nodulose eg. Mango ginger, *Cyperus rotundus* (Fig. 2.10).

Fig. 2.10
Nodulose roots

Fig. 2.11
Palmated roots

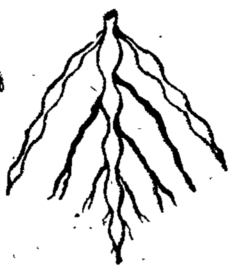

Fig. 2.12
Moniliform roots

(*d*) ***Palmated:*** When the roots are divided at their tips, they will appear like a palm and so described as palmated e.g. *Habenaria* (Fig. 2.11).

(e) *Moniliform:* Some roots are alternately swollen and constricted presenting a beaded appearance and this is described as moniliform. e.g. *Dioscorea alata* (Fig. 2.12).

2. *Prop roots:* e.g. Banyan tree (*Ficus bengalensis*). This is a large tree with a number of horizontally growing branches from which aerial adventitious roots grow downward into the soil. They increase in thickness and are like pillars, giving additional support to the plant. Long living banyan trees cover large areas by their spreading branches supported on a number of prop roots. (Fig. 2.13).

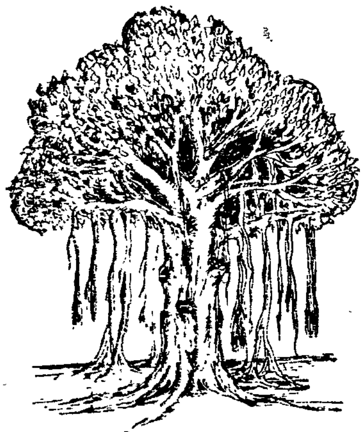

FIG 2.13 Prop roots

3. *Climbing roots:* Some plants cannot grow erect and therefore climb upon other large plants for their support. Such plants are called *weak stemmed plants*. They develop adventitious roots at their nodes which help to fix the plant to the support. Since these roots are helpful in the act of climbing they are called climbing roots. e.g. Betel vine (*Piperbetel*, pepper) (Fig. 2.14).

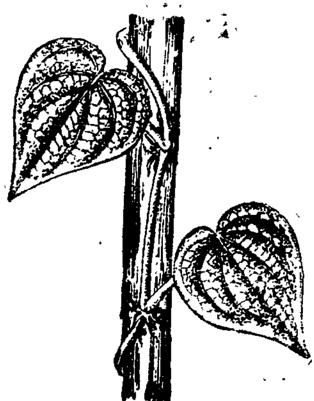

FIG. 2.14 Climbing roots

4. *Absorbing roots:* Some plants grow upon large plants without absorbing food materials from them. Such plants are known as *epiphytes* e.g. *Vanda*. These epiphytes develop a special kind of aerial roots which hang freely in the air. Each hanging root is surrounded by a spongy tissue, called *velamen* which absorbs moisture from the atmosphere (Fig. 2.15).

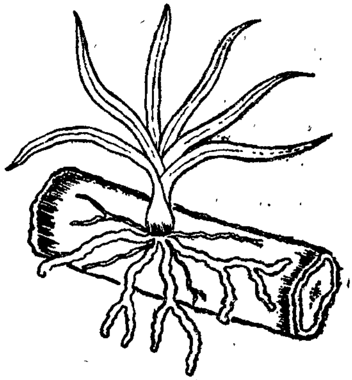

FIG. 2.15 Absorbing roots

5. *Respiratory roots:* Some plants grow in salt marshes. Some of their lateral roots grow above the surface of the water. Such roots contain numerous air spaces inside and have many small openings at their surface. Exchange of gases can

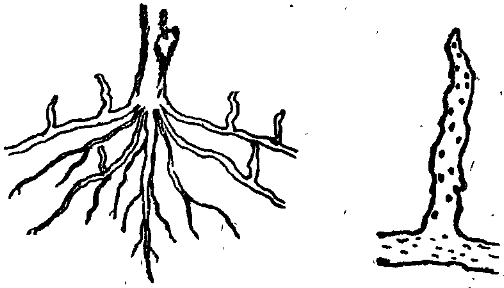

FIG. 2.16 Respiratory roots

take place through these roots. Since they are useful in respiration they are said to be *respiratory roots*. e.g. *Avicennia, Rhizophora*. (Fig. 2.16).

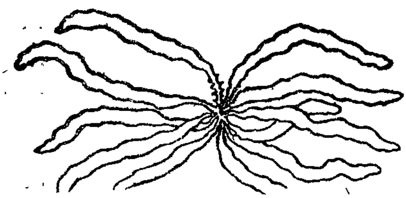

FIG. 2.17 Photosynthetic roots

6. *Photosynthetic roots: Taeniophyllum* is a leafless, stemless epiphytic *orchid*. There are no normal green leaves in this plant. The roots develop chlorophyll which are the sole photo-

synthetic organs of the plant to carry out assimilation. They are also called assimilation roots (Fig. 2.17).

7. *Stilt Roots:* Some plants like (screw-pine) *Pandanus foetidus* grow in loose soil on the edges of tanks and marshes. Short roots grow obliquely downwards from near the base of the stem. These roots act like stilts providing additional support to the stem (Fig. 2.18). The adventitious roots growing from the lower nodes of cholam and maize act in a similar way.

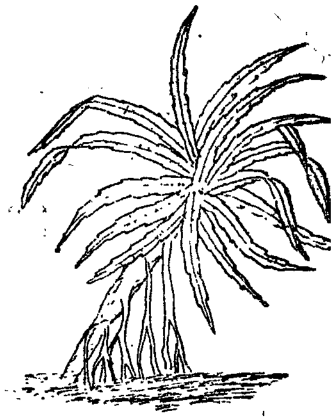

FIG. 2.18 Stilt roots

TISSUES

(ANATOMY)

The microscopic examination of the plant body of any higher plants informs that it is made up of countless number of and a variety of cells. A group of cells having a common origin, development, position, structure and function becomes a particular type of tissue. The different kinds of tissue are all arranged at the same time in a particular pattern and in varying combination and proportion in any given organ and also with respect to each other. Variations observed in these respects often reflect the characteristic features of a species. In such an organization and the arrangement of tissues, a combination of both living and non-living (dead) tissues can be seen (Figs. 3.33;3.38;) forming a republic and both discharge in unison their respective roles towards the welfare of the plants. Before we study the internal structures of the important plant organs and the tissues present in them in detail, let us have a preliminary understanding of the general characteristics of different important kinds of tissue. The tissues depending upon their homogeneous or heterogeneous composition are classified for the sake of convenience into simple and complex tissues. The

simple tissue is the one containing only one type of cells whereas in a complex tissue more than one type of cells is present.

I. Simple Tissues

1 *Parenchyma.* Parenchyma cells are the simplest cell type. The cells are living containing cytoplasm and nuclei. The cell walls are usually thin and sometimes thick. They appear hexagonal (Fig 2.20) or rounded in transections (Fig. 2.21) and arranged with or without intercellular spaces (Fig. 2.20; 2.21;) Parenchyma is also the commonest tissue and widely distributed to a greater or lesser extent in every organ and throughout the plant body. In other words, this tissue is predominant in cortex, pith, primary and secondary xylem (wood) and phloem of every organ and the endosperm of seeds. Parenchyma cells in their simplest unspecialized conditions resemble a particular geometrical model having 14 sides (facets) and such a model is called orthic tetrakaidecahedron (Fig. 2.19). But the cells are usually variable in shape and under such situations the number of sides may appear lesser than the typical number. The xylem parenchyma cell is either elongated or subdivided to form a strand (Fig. 2.24). Because of their living condition the cells are capable of undergoing further division, growth and modifications. Parenchyma is credited with a variety of functions depending upon their location within and with respect to the organ as follows: photosynthesis (mesophyll; chlorenchymatous hypodermis of young aerial organs); food storage (underground stems); water storage (succulent stems); wound healing and the development of adventitious roots and buds. Considering the parenchyma from the above mentioned stand points it appears to possess immense potentialities in terms of growth, development, differentiation (physiological and morphological changes occuring in a cell, tissue, or organ usually resulting in a specialized condition) and functions. Therefore the parenchyma cell is said to have total potentiality.

2. *Collenchyma.* This is one type of mechanical tissue present in the peripheral parts of aerial organs namely young stems, petioles and ribs of lamina (Fig. 3.87; 3.92) but usually absent

in underground organs and older parts. This tissue develops either continuously (Fig. 3.29, 3.33) consisting of few to several layers of cell or in the form of discrete strands. The individual cells of the tissue are more or less elongated characterized by unevenly thickened primary walls (Fig. 2.32). The cells are living containing protoplasts and thus showing a capacity for further growth and division. The more common form of collenchyma is known as angular collenchyma (Fig. 2.25). This is characterized by the wall thickenings occurring in vertical strips at the junction of cells (Fig. 2.32). As a result of this kind of thickening, the intercellular spaces become either small or totally lacking (Fig. 2.32.) The cell walls show finely lamellated thickenings which are due to the successive alternate deposition of cellulose rich and pectic poor layers. The high percentage of pectic substances (a group of complex carbohydrates) in their walls accounts for their correspondingly high hydrated condition. Collenchyma tissue imparts strength and elasticity to the organs concerned.

3. *Sclerenchyma*. This is another type of mechanical tissue. Under this general term sclerenchyma two categories are recognieed based upon their respective size factor, distribution and mode of origin. In one category of sclerenchyma, the individual cells are either isodiametric (with diameters equally long and thus regular in form (Fig. 8.7) or polymorphic but in either case they are usually broader than long except a few unusual fibre like elongated types. They develop as a result of further modifications of the existing parenchyma cells or from special initials of their own. The cell walls possess simple or ramiform (branched) pits (Fig. 8.7). They are present in a diffuse manner in any part of the ground tissues, cortex, at vein endings of the leaf, seed coat (testa), pericarp (fruit wall) and barks. This category of sclerenchyma is known as the sclereids. The second category of sclerenchyma known as the fibres (also spelt as fibers) are usually and considerably longer than broad (narrow) with tapering ends (Fig. 2.30). The lateral walls possess bordered pits (minute openings arched over by the secondary wall thus forming borders) which may be well developed or much reduced (Fig .2.30; 2.31) or even absent. The fibres develop from definite meristems (tissues

concerned with the formation of new cells by division). The fibres occupy a definite position within an organ such as hypodermis, secondary xylem and phloem, sheaths of vascular bundles. However both sclereids and fibres are characterized by exceedingly thick, usually lamellated cell walls which are differentiated into primary and secondary wall layers (Fig. 2.30; 2.31). The sclereids give hard, incompressible texture to the organs concerned while the fibres support and hardness.

4 *Epidermis.* The epidermis is the outermost surface layer of every organ of the primary plant body. But in the older part this layer is replaced by substitute layers of different kind, structure and origin. The cells are arranged in such a way that they form a continuous layer arranged without intercellular spaces (Fig. 3.91; 3.92). The cells are either uniform in size, arrangement and shape (Fig. 3.92) or more frequently variable (Fig.3.91). However, the epidermis being the outermost layer directly exposed to the environment is overlaid with a waxy substance known as the cutin which ultimately develops a thick or thin layer known as the cuticle (Fig. 3.91). The mode and process of formation of cutin is called cutinization and that of the cuticle is known as the cuticularization. Cuticle is however wanting in the epidermis of the underground organs and submerged portions of water plants. Because of these structural characteristics the epidermis is well known for its efficiency as a protective layer. Besides this protective function, it also takes part in exchange of gases and water loss through stomata (photosynthesis, respiration and transpiration). The continuity and homogeniety of the epidermis is usually interrupted by the development of stomata (young herbaceous stems and leaves) and hairs (trichomes). The cell walls are straight or undulate (wavy), thick or thin and the thickness of the walls may be even throughout or uneven. Cells usually possess protoplasts and therefore they possess a variety of substances such as anthocyanin pigments (soluble in water and responsible for red. blue and purple colours), tannin (group of phenolic derivatives, brown in colour), oils, crystals of different chemical composition, silica etc. In some shade loving plants chloroplasts are also present. Each stoma (pl. stomata) possesses a pair of highly specialized, structurally modified cells known as guard

cells enclosing in between minute microscopic opening which leads internally into a substomatal chamber (Fig. 3.88). The stomata are in turn immediately surrounded by certain number of ordinary epidermal cells or cells which are totally different from the remainder and the latter are known as the subsidiary cells. However the cell walls of guard cells are unevenly thickened in such a way as to give rise to outer and/or inner horn like projections known as outer and inner ledges respectively (Fig. 3.88). Guard cells are living containing protoplasts and chloroplasts. They exhibit a mechanism regulating the opening and closing of the stomata and thus they are able to participate efficiently in certain important physiological processes (transpiration, photosynthesis and respiration).

5. *Phellem* (cork): The *phellem* occurs as substitute protective layers particularly in the older axial organs undergoing secondary growth. The phellem ultimately replaces the original epidermis of the primary organs. Therefore just as the epidermis the phellem also remains as a peripheral tissue. The continuity of the phellem layers is interrupted by small opening visible to the naked eyes known as the lenticels and they are filled with loosely arranged filling or complementary cells (Fig. 8.10; for other details see under stem). The phellem cells are tubular or isodiametric and compactly arranged without intercellular spaces (Fig. 8.11). The secondary walls of phellem cells are suberized (impregnated with fatty substance known as suberin). The cells sometimes contain tannin also. The protoplasts disappear at maturity of the cells, and thus become a dead tissue. Because of these structural characteristics, the phellem or cork not only serves as an efficient protective layer but provides an excellent insulation for the underlying tissues. It is also impervious to water and gases.

II. Complex Tissues

6. *Vascular cambium.* The vascular cambium (adjective 'vascular' used here to distinguish it from another cambium (phellogen) concerned with the formation of non-vascular tissues such as phellem etc.) is present in all axial

organs of gymnosperms, shrubs and tree species of dicotyledons except herbaceous dicotyledons and monocotyledons. As correctly defined recently, it is considered to represent a multiseriate or layered zone. This zone consists of dividing cells. These dividing cells are more correctly called initials because they not only perpetuate themselves but give rise to new cells by division. These dividing cells represent not only the fusiform and ray initials which are the real ones belonging to the vascular cambium but also the phloem and xylem mother cells derived out of the former now functioning and behaving as initials. The initials are capable of dividing both anticlinally (at right angles to the axis of the dividing cells) and periclinally (parallel to the axis of the diving cells. Fig. 2.22; 2.23). This important zone of complex organization is known as the cambial zone (Fig. 2.42; 3.33; 3.41). Such dividing cells are sandwiched between the developing secondary xylem and phloem (Fig. 3.41). Out of these dividing cells, the ray initials are isodiametric (Fig. 2.23) and produce ray tissues which are oriented at right angles to the axis concerned and are part and parcel of the secondary xylem and phloem. The ray initials, by producing ray tissue known as the ray parenchyma, builds up the radial, horizontal or transverse system (Fig. 3.47). On the other hand the fusiform initials are usually elongated with tapering ends and having more or less 18 facets (Fig 2.22). Within a given vascular cambium the fusiform initials always outnumber the ray initials. All the vertically aligned components of the secondary xylem and phloem are produced by the fusiform initials, and thus the axial, vertical or longitudinal system is organized (Fig 3.47). The vascular cambium is lateral in position with respect to the organ concerned. The periodical increments of both secondary phloem and xylem cause the progressive increase in the girth of the concerned organs. At the same time the fusiform and the ray initials also undergo division (anticlinal) resulting in the multiplication of initials (Fig. 2.22; 2.23). By this method, the circumference of the vascular cambium is also increased thereby enabling the vascular cambium to keep pace with the increasing girth of the organs. Thus, it is interesting to observe the occurrence of two types of cell division within the vascular cambium namely one type of division (periclinal

Fig. 2.22) which gives rise to the formation of derivatives of secondary xylem and phloem and the other type of division (anticlinal Fig. 2.22) to the multiplication of initials themselves. The initials possess cytoplasm, nuclei and are highly vacuolated.

7. *Xylem.* This is the principal water and solute conducting tissue having a complex organization, in the sense that it contains vessels or tracheids, fiber tracheids or libriform fibres, xylem or axial parenchyma and ray parenchyma. The xylem is classified into primary and secondary based upon the source from which it is derived, age of the organ and the structural characteristics particularly of its tracheary elements. The xylem that is formed by the procambium (primary meristem giving rise to primary vascular tissues) in a young organ consists of two kinds of elements namely protoxylem and metaxylem elements. The first formed elements of the primary xylem are known as the protoxylem and the latter formed ones are called metaxylem (Fig.8.9). The protoxylem elements are usually characterized by annular, helical, spiral and scalariform thickenings (Fig.8.9). These thickenings refer to the secondary wall which is internally superimposed upon the primary wall in the above mentioned pattern. On the other hand the elements of the metaxylem possess reticulate thickenings and pitted elements (Fig. 8.9). Likewise the length and the width of protoxylem and metaxylem elements seem to indicate differences between them. The protoxylem elements are usually narrower (Fig 8.9) and considerably longer than those of the metaxylem, although such variations in them are not clear cut but seem to be rather gradual (Fig. 8.9). The various elements of the secondary xylem are produced by the vascular cambium in the older organs. The vessels possess perforations at the end walls (Fig. 2.24) which may be simple or multiple. The former condition is known as simple porous and the latter scalariform porous (Fig. 8.8) and this issue of the important and characteristic qualifications of the vessels. Because of this particular feature, the vessels are also known as the perforate elements in contrast to the fibres and tracheids in which they are totally wanting and hence the latter are known as the imperforate elements (Fig 2.28). The vessels, fibres, and tracheids are characterized

by the presence of a continuous layer of secondary wall. The lateral walls are usually provided with minute openings known as the bordered pits (Fig 2.26;2.27; 2.28;2.29) The bordered pits with respect to the relative abundance, size, shape and pattern of distribution show variations. The vessel is a composite structure consisting of more than one similar unit or element arranged one over the other in a vertical manner (Fig. 3.34) and the individual unit is known as the vessel member or element (Fig. 2.26). However the protoplasts disorganize when the elements become fully differentiated and thereby becoming dead.

Tracheids are elongated cell types with narrow lumina, angular in cross section and overlapping with each other by their tapering end walls (Fig. 2.28). They possess well developed bordered pits (Fig. 2.29). The tracheids are dead cells when they become fully differentiated. They discharge dual functions namely conduction of water through bordered pits (in the absence of terminal perforation) and support.

Ray tissue is formed by the ray initials of the vascular cambium. This tissue is also complex because of the usual occurrence of two types of cells called upright and procumbent cells (Fig 3.47). In transverse sectional views (when the secondary xylem is tangentially cut) the rays usually appear to be spindle shaped or somewhat elliptical or in the form of a linear file of cells. On the other hand, in longitudinal sectional views (when secondary xylem is radially cut) they appear to have a tiered arrangement of cells of varying thickness (Fig. 3.47) However the rays are composed of living cells and usually contain tannins, crystals, oils. They are supposed to take part in radial transport and storage of reserve metabolic byproducts. For other xylary tissues (parenchyma, fibres) see above.

8. *Phloem.* Just like the xylem, the phloem also is one of the important components of the vascular tissues taking part in the conduction of food materials to different parts of the plant. As a complex tissue, phloem contains sieve elements (sieve tubes or sieve cells), albuminous or companion cells, phloem parenchyma, phloem fibres and phloem rays. Depending on the

source from which the tissue is derived and the age of the organs this is classified into primary and secondary phloem. The primary phloem is derived from the procambium and present in the organs which are still young. On the other hand, the secondary phloem originates from the vascular cambium after the maturation or full development of the organs.

Sieve elements are the principal components of primary and secondary phloem. The sieve element is called so because of the presence of minute perforations known as the sieve areas at its lateral and end walls thus bearing a semblance to the sieve plate of the household item. The sieve elements develop specialised sieve areas in the form of distinct sieve plates particularly in their end walls (Fig. 3.35; 3.37) bearing few to several sieve areas (unspecialized) on their lateral walls. They are known as the sieve tubes which are usually reported in angiosperms. Vertically arranged series of this kind of cells resembling conduit pipes is called the sieve tubes and the individual component of this series is known as the sieve tube member or element (Fig. 3.35; 3.36). However, it is interesting to know that the sieve elements appear to be remarkable cell types because of their complicated developmental history and the absence of nucleus (which is necessary in a living cell) when fully differentiated (enucleate) (Fig3.35;3.36). Thus a fully developed sieve element is considered to be a living cell type despite the absence of a nucleus and in this respect it is an unique model of its own without a parallel among the cell types known. The walls are relatively thin but usually having unlignified thickening. This thickening is laid in a wavy manner and presents a pearly white lustre and hence it is known as the nacre. The sieve element becomes devoid of all the original cytoplasmic contents except a thin peripheral layer of cytoplasm and slime (proteinaceous substance) traversing the entire cell when fully developed (Fig.3.35). Each pore (Fig 3.36) in the sieve plate is traversed by cytoplasmic strands thereby establishing connection and communication with cells lying below and above. The pores are ensheathed by a cylinder of callose (a kind of carbohydrate) as in Fig. 3.37. When the sieve tubes are in a functioning stage, the callose exists only as a tubule (Fig. 3.37) but at the non function-

ing stage the callose develops to such an extent as to block the pores and camouflage even the entire sieve plates(Fig 3.36).

The companion cells are now considered as specialized parenchyma like cells. They are always associated with sieve tubes but occurring in variable number and position (Fig. 3.36) Developmentally, the companion cells are considered to be the sister cells since both these cells and the sieve tubes develop from the same source. But unlike the sieve tubes, these are nucleated till their death. The companion cells help the sieve tubes in regulating the translocation. According to recent findings, the companion cells resemble the secretory cells. For phloem parenchyma, fibres and rays, see above.

Anatomy of The Root

The roots usually represent the underground organ of the tracheophyta. But there are examples in which the roots develop adventitiously from different organs and positions of the plant namely stem (climbing roots of *Piper nigrum*), branches (prop roots of *Ficus benghalensis*), leaves (epiphyllous roots of *Kalanchoe* sp.) and roots (pneumatophores of *Avicennia officinalis*) or as in the case of parasites (*Loranthus* sp.) they are present as modified structures known as the haustoria. Roots of certain gymnosperms and Fabaceae (Papilionaceae) become modified due to the invasion and influence of bacteria and fungi thereby causing root nodules and mycorrhizae respectively. Normally in seed plants, the radicle of the embryo develops directly into the tap root which in turn gives rise to lateral roots. As a result of this kind of development a distinct profusely ramifying root system is established in course of time. In certain cases of seed plants particularly among the monocotyledons, although the radicle develops into a primary root it is soon replaced by adventitious fibrous roots which are emanating from the bases of the stems. Although the roots in the majority of cases appear to be part and parcel of the plant body and are present in continuation with the main leader of the shoot system, judged from the standpoint of development, morphology, anatomy and physio-

logy, they appear to be different organs Roots in general and under normal conditions give anchorage and serve as organs of absorption. But under certain special conditions, in addition, they serve as organs of storage as in *Manihot utilissima* (Tapioca), additional support in *Ficus benghalensis* (Banyan tree), climbing in *Piper nigrum* (pepper), assimilation in *Vanda tessellata* (epiphytic orchid), aeration in *Avicennia officinalis* L. (White mangrove; Upattha) and symbiosis in *Erythrina indica* (Coral tree; Kalyana Murungai). However the study of anatomy of the root with the help of *Ricinus communis* (castor) may convince how the internal organization, the different types of tissue and tissue system maintain a compromise with respect to the functions discharged by the roots.

Primary Structure

Root cap. The growing and advancing tips of the roots inside the soil are protected usually by a few to several layers of parenchymatous cells. These cells form the root cap or calyptra (Fig. 2.43). The root cap or calyptra is formed by a meristem known as the calyptrogen (Fig. 2.43). The cells are living and contain amyloplasts (colorless plastids forming starch) producing amylum or starch. The root cap is supposed to protect the young delicate growing tips from damage. The cell walls of the root cap cells possess mucilaginous consistency due to the presence of pectic substances in them. The root cap is also supposed to be the potential site for causing geotropic curvature of the roots. As the root tips advance, the outermost layers of cells are successively sloughed off from time to time and new layers originate and are added on from within.

Rhizodermis or *epiblem*. This is a single layer of thin-walled cells arranged in a closely packed manner without intercellular spaces (Fig 2.33). Sometimes this layer is cutinized or suberized in case it is persistent. The opinion of some anatomists who prefer to distinguish the root epidermis from that of the shoot is to designate the former by separate terms rhizodermis or epiblem. This view appears to be reasonable because its origin, function and structure differ from that of the shoot. In other words, the rhizodermis or epiblem is neither homologous

with (in terms of morphology and structure) nor analogous with (in terms of functions) the epidermis of other organs. Therefore, the terms rhizodermis or epiblem is adopted here.

Depending upon the persistence or permanence of this layer the rhizodermis becomes suberized or cutinized or the outermost layer or layers of the cortex lying immediately beneath the rhizodermis may be differentiated into layer of cells with suberized walls. A layer of this kind is known as exodermis. The exodermis develops after the original rhizodermis is sloughed off. When present, this may consist of one to several layers of cells. According to some authors this is supposed to represent the hypodermis in a topographical sense, although it is both histochemically and structurally specialized.

A typical characteristic of the rhizodermis is its capacity to develop root hairs. The root hair region is just one to few centimetres away from the tip. A root hair develops as a direct prolongation of some or all of the rhizodermal cells (Fig. 2.33). If it is formed from a special cell distinct in size from the neighbouring cells and it is known as the trichoblast.

Cortex. This region of the root is delimited outwardly by rhizodermis and inwardly by endodermis. Cortex usually consists of homogeneous layers of parenchyma. The arrangement of parenchyma cells may be radial and concentric (Fig. 2.33; 2.43) or loosely arranged. The cells are frequently associated with intercellular spaces. The cortex shows variations with respect to the subterranean environmental conditions of the habitats. For example, in wet or marshy habitats, the cortex develops air cavities which are formed either schizogenously (by separation of cell walls along their middle lamella or lysigenously (by disorganization of existing cells Fig. 2.43) or rexigenously (by tearing of cells). Some times, the arrangement of air cavities formed by the disintegration of the radiating rows of parenchyma cells conforms to radial alignment similar to that of the latter (Fig. 2.43). In the case of monocotyledons, sclerenchyma is developed to varying number of layers either in the outermost cortex or next to the endodermis (Fig. 2.45). In palms, isolated fibre bundles are scattered in the cortex. Starch is often present.

Endodermis. This represents a single layer of structurally specialized cells and is located on the innermost limit of the cortex (Fig. 2.33;2.34). The endodermis is present quite characteristically and universally in all roots of different kinds. Each endodermal cell is characterized by a strip of thickening on its anticlinal (radial) walls and it is known as the Casparian strip or band (Fig. 2.34;2.35). The thickness and the prominence of the thickenings vary according to the stage of development of the endodermis. In roots undergoing secondary growth, the endodermis is either crushed or stretched or totally discarded or developing further in order to keep pace with the expanding vascular cylinder. But at the same time in the absence of any secondary growth as in the majority of monocotyledons and a few dicotyledons, the endodermis remains as such by undergoing changes only with respect to their own cell walls and not any other changes as mentioned above The endodermal cells facing the phloem are thick-walled and those confronting the protoxylem elements possess only Casparian strips on their anticlinal walls Such cells are called 'passage cells' through which the materials pass between the cortex and the vascular cylinder. It should be remembered that an endodermis is wanting in stems and other aerial organs and even if present, the one possessing all the above mentioned characteristics is absent.

Pericycle This is usually present as a single layer of parenchyma cells internal to endodermis (Fig 2.34). But in the case of monocotyledons lacking secondary growth, the pricycle is composed of thick-walled cells (Fig 2.45) The pericycle is also known as the pericambium because of its subsequent meristematic activities concerned with the development of lateral roots, phellogen or cork cambium and cambium in all roots showing secondary growth. Pericycle is always present in roots except in those of water plants and parasites. Apart from its meristematic activities, the pericycle is supposed to represent the outermost limiting layer of the stele (the central cylinder of the axis comprising the vascular system and the associated ground tissue) and also as a layer which is part and parcel of the stele on the basis of their common origin with stelar components.

- *Vascular cylinder* (*stele*). The vascular tissues together with ground tissue represented by pericycle, interfascicular regions and pith comprise what is known as the central cylinder of the axis (stem and root) or stele The stele is recognized as a morphologic unit of the plant body. The vascular tissues in a young root are represented by primary xylem and primary phloem. In contrast to the stems, they are quite characteristically arranged not in the same radius but on different radii. In other words, the primary xylem and primary phloem regularly alternate with each other (Fig. 2.33;2.34;2.44;2.45). This kind of arrangement is known as the radial arrangement which is a characteristic feature of all the roots, just as the reverse condition known as collateral arrangement is characteristic of the stems. Under this radial arrangement, the vascular tissue occurring in the form of discrete strands occupy the peripheral part of the vascular cylinder or stele, in which case the central part of the root is distinctly recognizable as parenchymatous pith (Fig. 2.33). In another form, root stele the xylem strands alone of project into the centre, thereby forming a central xylem core in which case a distinct parenchymatous pith is absent. Another anatomical distinction between the root and stem is observed with respect to the relative position of xylem elements namely protoxylem and metaxylem elements within each strand. In all roots, the elements of protoxylem lie near the periphery and abutting on the pericycle, while those of the metaxylem are a little away from the latter (towards the centre). Likewise the elements of protophloem and metaphloem of primary phloem reveal similar positional relationships. The xylem having this kind of orientation is known as exarch which is a characteristic universal feature of all roots. The reverse arrangement of protoxylem and metaxylem elements known as endarch condition is an inevitable feature of all stems. This particular anatomical feature together with radial arrangement of xylem and phloem stand out not only in contrast to the reverse situation (endarch xylem and collateral arrangement of vascular tissues) present in the stems, but also are useful and dependable in the matter of identification of these two organs under any circumstances. The first formed elements of vascular tissues represent the protoxylem and protophloem poles respectively. Based on the number of protoxylem poles, the

roots are designated as monarch (one), diarch (two), triarch (three), tetrarch (four) (Fig. 2.33), pentarch (five) and so on. Each one of these said conditions represents the usual feature of the dicotyledonous roots. When the number of protoxylem pole is greater than these numbers, as noticed in most of the monocotyledons, such roots are said to be polyarch (Fig. 2.36). The number of xylem strands in a given root, although emphasized as a sure mark of distinction between the monocots and dicots but this does not hold good since it is seen to be frequently variable depending upon the level of observation and examples. In this respect compare the primary structure of root of *Ricinus communis* with that of *Chloris barbata* and their respective figures thereof (Fig. 2.33;2.34;2.44;2.45).

DESCRIPTION OF PRIMARY STRUCTURE OF A DICOTYLEDON ROOT—*Ricinus communis L.* (castor) Fig. 2.33;2.34

Diameter of the root described is about 0.8 mm. The outline of the root is somewhat circular. There is a single layer of rhizodermis or epiblem (for adoption of these terms in lieu of epidermis, see above) which is equivalent to the epidermis of other authors The rhizodermal cells are variable in size and shape. The cells possess thin walls somewhat radially elongated and compactly arranged. Cortex is very broad and constituted of parenchyma cells with intercellular spaces among them. Endodermis is represented by a single compact continuous layer of cells which are rectangular or squarish in shape, variable in size and possess Casparian strip of thickenings on their radial walls. Pericycle is also a single layer of compactly arranged parenchyma cells varying in size and shape.

Vascular System: In terms of number of protoxylem poles the root is tetrarch. There are 4 strands of primary xylem regularly alternating with same number of primary phloem groups. As the primary xylem and primary phloem occupy separately alternating radii, the arrangement is said to be radial. So far as the orientation of the protoxylem elements is concerned, the xylem is exarch (protoxylem element is nearer to the periphery than that of the metaxylem which is close to the centre). As mentioned earlier, the radial arrangement of the components of the vascular tissues and the exarch xylem which are the tell

tale marks of the roots are present in this example. The primary xylem elements are somewhat angular in outline. The metaxylem elements are broader than those of the protoxylem and the former are arranged in a biseriate manner. Each primary xylem strand contains 6-8 radial rows of elements as seen in transection. A gradual reduction in the diameter of the elements commencing from the central metaxylem elements towards the peripheral protxylem elements may be observed, thus indicating one kind of difference in this respect between them. The primary phloem contains sieve elements and companion cells which appear smaller than the surrounding cells. Furthermore, they are somewhat polygonal in outline and compactly arranged. The ground tissue (pith) is parenchymatous, the cells of which are thin-walled, somewhat variable and compactly arranged.

DESCRIPTION OF THE STRUCTURE OF A MONOCOTYLEDON ROOT—*Chloris barbata* Sw. (Kodai pullu; Sevaragu pullu; Common grass) (Fig. 2.43, 2.44).

Diameter of the root described is 0.9-1.0 mm. *Rhizodermis* consists of thin-walled cells which are variable in size and shape and some of them develop unicellular root hairs. *Cortex* is recognizable into 3 zones; the outer zone consists of 2 layers of tangentially elongated somewhat thick-walled sclerenchymatous cells; the middle zone is broad and characterized by several air-cavities which are formed as a result of the dissolution of rows of parenchyma cells (lysigenous origin). It may be noted that the development of air-cavities is rather gradual and progressive depending upon the age of the roots. In very young roots they are absent but instead, the entire cortex is solid being composed of parenchyma cells of which are all arranged in radiating rows. Since the air-cavities are lysigenously formed at a later stage at the expense of the parenchyma which is present in radiating rows their disposition also conforms to similar pattern. Furthermore, the air-cavities are separated by radiating rows of parenchyma (unaffected). The inner cortex consists of 2 layers of narrow tangentially elongated cells. *Endodermis* is single layered. Cells are rectangular with uniform thickening throughout ('0' type). *Pericycle* is made up of single layer of cells which are larger than

those of the endodermis. The cell walls are thick, unlike those of the pericyclic cells of the dicotyledon roots. *Ground tissue* is sclerenchymatous and some of its cells contain tannin.

Vascular system. The primary xylem and primary phloem contain 5 units in each and they are radially arranged but a little away from the pericycle. Metaxylem vessel elements are rounded in outline having a diameter of 20 μm ($1\mu = \frac{1}{1000}$ mm.) Protoxylem elements are not easily distinguishable. Metaphloem consists of 2-3 sieve tube elements in each unit and as many companion cells.

Mechanism of Secondary Growth

The mechanism of initial formation of vascular cambium in roots is different from that of stems although the secondary tissues that are eventually formed reveal almost the same mode of formation and pattern of arrangement as in the case of stems. The vascular cambium originates first from a layer of cells situated immediately internal and subjacent to primary phloem (Fig. 2.37). Likewise the pericyclic cells opposite to protoxylem poles divide and differentiate a little later into vascular cambium (Fig. 2.38). Thus the genesis of the vascular cambium as far as the root is concerned is both spatially and temporally discontinuous. Furthermore the vascular cambium appears at as many different loci as there are phloem and xylem strands before it forms later as a continuous layer (Fig. 2.37, 2.38). The procambium which is present on the inner side of the phloem differentiates into vascular cambium and starts dividing periclinally. This results in the formation of derivatives on its either side. The derivatives falling towards the centre, differentiate into secondary xylem and those towards the primary phloem side into secondary phloem (Fig. 2.39). In contrast to the behaviour of the vascular cambium which is functioning on the phloem side and the tissue types (vessels, fibers and parenchyma) derived therefrom, the vascular cambium of the pericyclic origin present opposite to the protoxylem pole divides and gives rise to ray tissue only (Fig. 2.41, 2.42). Therefore, the number of such rays appears to be directly proportional to that of protoxylem poles (Fig. 2.41). In certain examples such a

situation and relationship may not exist. However, as the vascular cambium functions in the above said manner, it extends laterally and becomes a continuous layer (Fig. 2.39; 2.40). At this initial stage of its becoming a continuous layer, the cambial ring appears to be lobed or wavy following the original position and arrangement of primary xylem and phloem (Fig. 2.39). However, the waviness in the contour of the vascular cambium becomes soon rounded off and circular (Fig. 2.40). Because the vascular cambium on the phloem side starts functioning earlier and adds more secondary xylem derivatives than the cambium functioning opposite to the protoxylem pole. In other words, due to the formation of more of secondary xylem on the phloem side, the position of the functioning cambium is now shifted more and more towards the periphery. Thereby it gradually comes to occupy the same level as that of the cambium at the protoxylem pole which starts functioning later. The results of the cambial activity is that primary xylem is retained as such without any change while the primary phloem becomes crushed and obliterated and finally replaced by the newly formed secondary phloem. From the moment the vascular cambium assumes a continuous ring like contour, its activity and the formation of derivatives are similar to those of the vascular cambium of the stems which undergo secondary growth. The vascular cambium in the form of a regular ring divides periclinally and contributes derivatives on its either side. The inner derivatives differentiate into secondary xylem and the outer ones into secondary phloem. Both secondary xylem and secondary phloem form a continuous tissue. At this stage, the roots resemble superficially a woody stem except the presence of exarch primary xylem in the centre which can still be recognized (Fig. 2.41). Despite the similarity between the dicot stems and roots in terms of woodiness and secondary tissues, the latter can always be satisfactorily distinguished from the former by virtue of exarch primary xylem preserved in the centre (Fig. 2.41).

The cells of the pericycle divide after the formation of secondary tissues has been inaugurated. The outer derivatives of the dividing pericylic cells function as the phellogen or cork

cambium. The derivatives of the phellogen falling towards the outside differentiate into phellem or cork and those towards inside into phelloderm or secondary cortex. Due to the activity of the phellogen and the increments of its derivatives, all the original primary tissues such as endodermis, cortex and epidermis get sloughed off and now the products of phellogen occupy their places.

SECONDARY STRUCTURE—see under stem.

Differences between monocot and dicot roots: Although several points of differences are advocated to differentiate monocot roots from those of dicots, majority of them does not work satisfactorily, because such presumed differences are all based on a few representative examples and inadequate samplings and observation. On the other hand, if a large number of examples under each group of plants are surveyed and studied, the only differences that could be advanced and recommended are, in the first place, the monocot roots do not undergo secondary growth while those of the dicots show secondary growth to a greater or lesser extent, and in the second place, the pericycle in the monocot roots is constituted usually of dead cells, while that of the dicot roots is constituted of living cells which are capable of becoming meristematic at a later stage.

Physiology of the Root System

In general, the normal functions of roots are:

(1) anchoring the plant firmly to the substratum

(2) absorption and conduction of water and mineral salts and

(3) storage of food.

1. ANCHORAGE

Plants that are growing in the ground need roots for their establishment. Roots penetrate the ground and branch to fix the plant firmly in the soil.

2. ABSORPTION OF WATER

Plants are in need of water for performing various functions. Water is absolutely essential for the metabolic activity of protoplasm. Water acts as a solvent for different kinds of salts and gases and it is also the medium which is essential for most of the chemical reactions of living protoplasm.

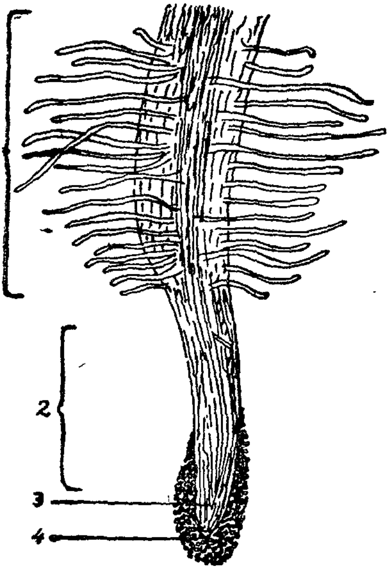

FIG 2.45(A). Tip of young Roots showing the different zones
1. Root hair zone 2. Zone of elongation 3. Meristematic zone 4. Root cap

Land plants absorb water from the soil mainly through roots. Submerged aquatic plants absorb water throughout their surface. The absorption of water does not take place from the entire surface of the root. Only younger portions of the root near the tip (root hair region) absorb water and mineral salts.

In a young root, four distinct regions or zones are distinguishable. At the extreme tip is the root cap which covers the growing point. Just above the root cap is the meristematic region, where maximum cell division occurs. Behind

this is the zone of elongation where the root grows in length. *Above this region there is a zone which bears the root hairs.* The root hairs are the main organs of absorption of water. Behind the root hair zone lies the mature part of the root (Fig. 2.45 A).

A root hair is a tubular outgrowth of an epidermal cell of the root. The cell wall of the root hair is made up of cellulose. It encloses cytoplasm which contains a nucleus. The cytoplasm forms a lining layer immediately inside the cell wall. There is a large vacuole in the centre. The vacuole is filled with cell sap which is a solution of salts and organic acids dissolved in water. The wall of the root hair is mucilaginous and therefore it sticks to the soil particles. (Fig. 2.46).

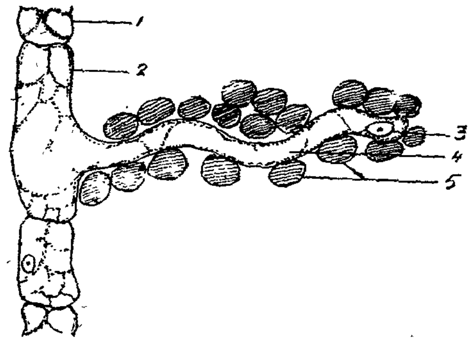

FIG. 2.46 Structure of the Root hair
1. Cell wall 2 Cytoplasm 3. Neucleus 4. Vacuole 5. Soil particles

Root hairs are short lived structures. As old root hairs die, new root hairs continue to develop in the younger part of the root. Thus they are able to come in contact with new supplies of water in the soil.

Absorption of water by the root hair takes place chiefly by means of a physical process called osmosis and to some extent by imbibition.

Imbibition

Imbibition may be defined as the soaking up of a liquid in solid materials, particularly in dry or semi-dry conditions. The cell wall and the protoplasm absorb water by imbibition. The swelling of dry seeds in water and the swelling of doors and other wooden framework during rainy season are common examples of imbibition. Imbibition can occur only if there is an affinity between the liquid and the material. Thus rubber does not imbibe water but imbibes benzene.

Osmosis

Osmosis is the process of diffusion of a solvent (water) from a region of higher concentration to a region of lower concentration through a semi-permeable membrane. This can be demonstrated by a simple experiment.

A thistle funnel with a long stem is taken and a sheep's bladder, which is a semipermeable membrane, is tied round the mouth of the thistle funnel tightly. The funnel is filled with sugar solution. It is inverted and kept immersed in a beaker containing water. The initial level of the sugar solution in the stem of the funnel is marked and the set up is kept undisturbed. After sometime, the level of the sugar solution in the stem of the funnel rises. This indicates that water from the beaker has entered into the funnel through the sheep's bladder.

Sheep's bladder is a semipermeable membrane and allows only water molecules (solvent) and not the molecules of sugar (solute) to pass through it. The concentration of water in the beaker is greater than that in the funnel. According to the laws of diffusion, particles of different concentrations move in such a way as to equalise the concentration throughout. Thus more number of water molecules move from the beaker into the thistle funnel than those that could move from the funnel to the beaker. Such a passage of water through a semipermeable membrane is called osmosis (Fig. 2.47).

A comparison between the thistle funnel experiment and the root hair is helpful in understanding osmosis in plants. The thistle funnel may be compared to the root hair and

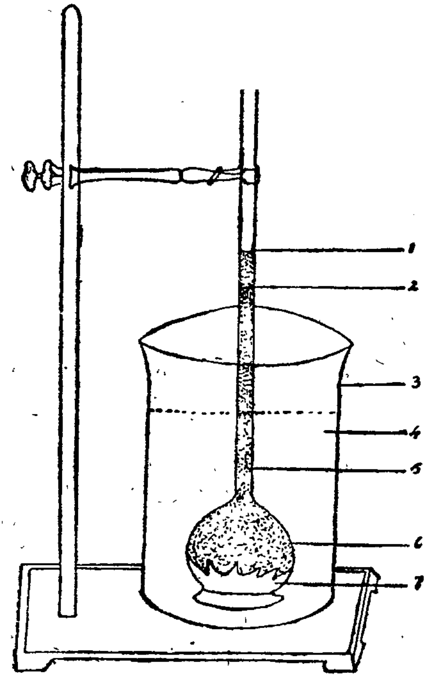

FIG. 2.47 Experiment to demonstrate Osmosis
1 Final level 2. Initial level 3. Beaker 4. Water 5. Sugar solution 6. Thistle funnel 7. Sheep's bladder

the sheep's bladder, to the lining layer of cytoplasm of the root hair. The sugar solution in the funnel corresponds to the cell sap and the water in the beaker, to the soil water. The cell sap in the root hair is, under natural conditions, of a higher salt concentration than soil water. Therefore water is taken in by the root hair through osmosis.

There are several factors that affect water absorption by roots. These factors are environmental and internal. The

environmental factors are (1) availability of soil water (2) soil temperature (3) concentration of soil solution and (4) aeration. Transpiration, metabolism etc. are the internal factors.

When water enters the root hair from the soil, the concentration of water in the cell sap of the root hair becomes higher than that of the cell sap of the inner cortical cell. Hence water from the root hair enters the outermost cortical cell by osmosis. In the same manner, it passes through many layers

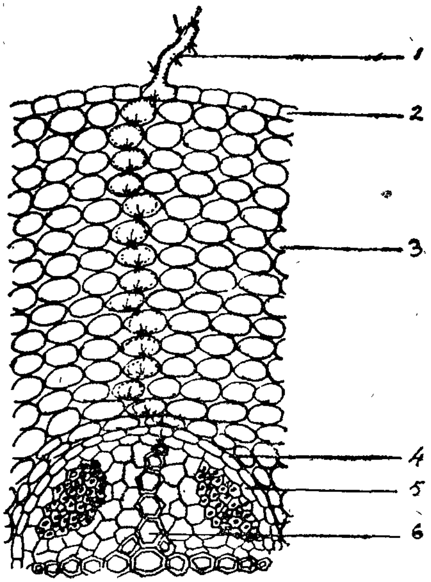

Fig. 2.48 Transverse section of root showing the path of water from the root hairs to the Xylem

1. Root hair 2 Piliferous layer 3. Cortex 4. Endodermis 5. Pericycle 6. Xylem

of cortical cells, endodermis and pericycle and finally reaches the xylem vessels. Due to osmosis, a pressure is set up in the root. This is called root pressure, which helps in the upward flow of sap. (Fig. 2.48).

Root pressure can be demonstrated by mercury manometer experiment.

A well watered pot plant is taken. Its stem is cut off under water about 3 or 4 cms above the soil level. A mercury manometer is attached to the cut end by means of a rubber tube. Care is taken to see that water completely fills the rubber tube up to the level of mercury in the manometer. The mercury level in the open end of the manometer is noted

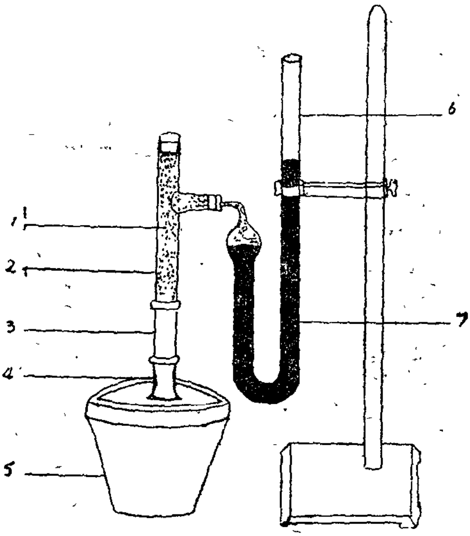

Fig. 2.49 Root pressure experiment
1. Water 2. Glass tube 3. Rubber tube 4. Stem 5. Pot 6. Manometer 7. Mercury

and the set up is left undisturbed. After a few hours, it will be noticed that the level of mercury at the open end of the manometer has risen up. Evidently sap exuding from the cut end of the stem forces the mercury upward. The exudation of water is due to root pressure. By finding the maximum height to which mercury is lifted, the root pressure of the plant can be calculated. (Fig. 2.49).

Absorption of Solutes

In addition to water plants take in a considerable amount of mineral salts also dissolved in it. The intake of mineral

salts is as important as that of the absorption of water for plants. Formerly it was thought that the mineral salts entered the roots along with soil water. But now it is known that the absorption of mineral salts is a process independent of the absorption of water. This is proved by experiments which show that the rate of absorption of water differs from the rate of absorption of the mineral salts. Moreover mineral absorption takes place nearer the tip of the root while the absorption of water takes place in the region of root hairs.

It is believed that salts are not absorbed as whole molecules but as ions. This is evident from the unequal absorption of the anions and cations of the same salt in the cell sap. For many years, botanists believed that mineral salts entered into the roots by diffusion. It is possible that limited quantities of mineral salts do pass into some kinds of cells by diffusion. But in general this is relatively an unimportant mechanism of absorption compared with others. At present, two other important mechanisms of mineral salt absorption are recognised: (1) the mechanism of ionic exchange and (2) the mechanism of salt accumulation or active solute absorption.

Mechanism of ionic exchange

The mechanism of ionic exchange involves an exchange of anions or cations within cells for ions of the same sign and equivalent charge in the exterior of the absorbing cell. The ionic exchange mechanism can be demonstrated as follows: If excised barley roots, which have absorbed radioactive K^+ ions from a solution, are placed in distilled water, none of the radioactive ions from the roots enter into the water. The cytoplasm of the root cells behave as if they are impermeable to the ions which entered the cells before their transfer to distilled water. But when similar excised barley roots are placed in a dilute solution of non-radioactive KBr, the radioactive K^+ ions move out of the root cells into the solution and at the same time the non-radioactive K^+ ions move into the cells from the solution. In this case, the cytoplasmic membranes are permeable to K^+ ions moving in both directions. Since the total amount of potassium in the external solution

remains unchanged, it is evident that radioactive K^+ ions have, *in effect*, exchanged places *with non-radioactive* K^+ ions in the solution.

It is understood from such experiments that the first step in the absorption of cations by the peripheral cells of the roots is an ionic exchange process. *In this process, the root appears* to give off and exchange H^+ ions for clay-bound nutrient cations. The cations then become bound to the cell membrane by absorption. The *root* can also absorb *anions in* exchange for free hydroxyl OH^- ions. Ionic exchange does not require the use of energy and is, therefore, supposed to, a passive physical process.

Mechanism of salt accumulation

The process is the accumulation of salts *in* the cells *in* concentrations many times greater than that of the same in the surrounding medium. It is probably the most important single mechanism of salt absorption and is also called '*primary* salt absorption'.

It has been observed that the alga *Nitella* accumulates potassium K^+ ions to a concentration far exceeding that of the surrounding medium. It has also been known for many years that certain marine algae are able to accumulate within their cells large concentrations of iodine, which occurs in exceedingly minute quantities in sea water. Despite the fact that the concentrations of iodine is much lower in the sea water than it is in the bodies of the algae, the cells of algae contitinue to absorb iodine. Absorption in such cases takes place against a concentration gradient i.e. from a region of lower concentration to a region of higher concentration for each ion.

The phenomenon of salt accumulation seems confined to cells which have the capacity for cell division and growth. As cells lose their capacity for growth, they also lose their capacity for mineral salt accumulation. This active solute absorption requires expenditure of energy, not only for the absorption of ions but also for the retention of ions within the

cells. This energy is supplied by the respiration of the absorbing cells. Accumulation of salts seems to depend upon the rate of respiration.

In this process, the ions enter into combination with some component of the plasma membrane which acts as a carrier. The ions and the carrier constitute the ion-carrier complex. The ion-carrier complex moves across the membrane. In the cytoplasm, this complex breaks up and releases the ions. This is known as carrier concept.

Absorption of salts depends on a number of factors like respiration of the root, rate of transpiration, light affecting photosynthesis, temperature, hydrogen ion concentration etc.

3. STORAGE

Roots also serve for the storage of food. Roots which become swollen and fleshy due to the storage of food materials are called root tubers. In radish, beet root, carrot etc. the tap root or the hypocotyl serves this function. In *Asparagus*, sweet potato etc., adventitions roots serve as storage roots. Many of the root tubers are edible. Both the cortex and the pith may be places of food storage. Roots may also store water.

Economic Importance of Roots

Roots are useful in many ways for our food, and medicine. They are also useful in yielding the tanning material and dyes which are widely used nowadays in leather and textile industries.

I. Food.

1. *Sweet potato: (Ipomoea batatus*—Convolvulacae). It is one of the crops of tropical countries. It is a herbaceous perennial with weak stems trailing prostrate on the ground. The thin adventitious roots gradually become fleshy tubers. There are

two types of tubers namely red and white. This can be cultivated in all types of soil but thrive well in sandy and lighter soils.

(a) The tuberous roots are an important source of starch. Besides starch it contains sugar, vitamin A, B and C.

(b) It is also used as laundry starch in paper and textile industries, confectionery, bakeries, and in the manufacture of cosmetics and adhesives.

2. *Beet root* (*Beta vulgaris* Chenopodiaceae). The plant is a native of Europe and is cultivated in India. It is a biennial herb with large fleshy tap roots.

Beet roots are rich in carbohydrates, proteins, minerals and A, B and C vitamins.

3. *Carrot* (*Daucas carota* Umbelliferae). The plant is a biennial herb with fleshy conical tap root. It is cultivated as a winter crop in India. It can be grown in all types of soil except clay. It is highly nutritious and contains carotenes, thiamine, riboflavin, vitamin C, D and E, phosphorus and calcium.

4. *Radish* (*Raphanus sativus* Cruciferae). Itis a native of Europe but is widely cultivated in India. It is a biennial herb with white or reddish tuberous tap root. Roots and leaves are eaten as vegetables.

II Medicine

Roots are also extensively used in the preparation of allopathic and Indian systems of medicine.

1. *Rauwolfia serpentina* (Apocynaceae): This is commonly known as Serpagandha due to its serpent like roots. It is found in the rain forests of India. It is a small erect herbaceous plant.

Dried roots contain reserpine and rescinnamine alkaloids.

It reduces blood pressure.

It is successfully given in the state of mental anxiety, hypertension and fear It is also used to cure mental illness.

2. *Colchicum autumnale* (Liliaceae): It is a herbaceous plant found in the Himalayas. The roots of the plant are used for the treatment of diseases of liver, spleen and rheumatism. When the drug is applied externally, it reduces the pain and inflammation. Colchicine extracted from the root is used to induce polyploidy, in plants.

3. *Ferula asafoetida* (*Umabelliferae*): This is a small herbacieous plant found in the cooler parts of India. It is a perennial herb. Asafoetida is extracted from the roots which aids digestion, and also used as a pain reliever and laxative.

III Tannin

This is a substance obtained from various plants which is widely used in the leather industry. Some of the tannins are extracted from the roots of plants like *Geranium wallichiana* and *Rumex hymenocephalus*.

IV Dyes

Dyes are colouring matters which are obtained from the roots of some plants. They are chiefly used in the textile industry and also for colouring paints, varnishes, leather, paper wood, food, cosmetics etc.

An yellow dye is extracted from the roots of *Morinda tinctoria*.

Chapter 3

THE SHOOT SYSTEM

A. STEM

Morphology

The shoot system is the portion of the axis of the plant, developing directly from the plumule. It consists of the stem bearing leaves, branches and flowers.

Characteristics of the stem

1. Stem grows away from the centre of gravity (negatively geotropic) and towards sunlight (positively heliotropic).

2. It is normally green in colour, when young.

3. The growing apex is covered over and protected by a number of young leaves which arch over it.

4. Branches develop from the stem exogenously.

5. Stem is provided with nodes and internodes.

6. Stems possess axillary and terminal buds.

Habits of plants

The habit of the plant is determined by the nature of its stem life span and the maximum height attained during its lifetime.

1. *Trees:* These are large plants with a single stout trunk usually with several branches and they are hard and *woody*. They are capable of growing to great heights and live many years e.g. Mango *Mangefera indica*, Coconut (without branches).

2. *Shrubs:* These are shorter than in stature and live for lesser number of years. These do not have a tall and thick trunk. e.g. *Hibiscus rosasinensis*.

3. *Herbs:* These are small plants with soft stems and live for one or two years. e.g. *Ruellia tuberosa*.

Duration of plants

Plants are classified into four groups according to their life-span and the nature of giving rise to flowers and fruits.

1. *Annuals* are plants which complete their *life-cycle* within a year or a season. Within this period they grow, reproduce and die. e.g. (Mustard) *Brassica juncea*, (paddy) *Oryza sativa.*

2. *Biennials* are plants which will live for two years. They attain their full vegetative growth in the first year and produce flowers and fruits in the second year after which they die. e.g. (Carrot) *Daulus carota*, (Radish) *Raphanus sativus*, (Beet root) *Beta vulgaris.*

3. *Perennials* are plants which will live for a number of years and develop flowers and fruits every year. e.g. Tamarind, Mango.

(Ginger) *zingiber officinale* is a *herbaceous perennial.* The aerial parts of these plants may die down every year at the end of the flowering season, but next year, again new shoots develop from their *underground stems.* Thus they live for a number of years.

Functions of the stem

1. *Conduction:* The water and the mineral salts absorbed by the root system are conducted upwards through the stem to different parts of the shoot system like branches, leaves etc. The food materials prepared by the leaves is conducted downwards through the stem to the roots and storage organs.

2. *Support:* The stem supports branches, leaves, flowers and fruits.

3. *Storage.* But some of the aerial stems like sugarcane and underground stems like ginger and turmeric store large quantities of food materials in them.

4. *Vegetative propagation:* Underground stems like ginger and turmeric and aerial stems of rose and jasmine are useful for multiplication without the help of their seeds which is known as vegetative propagation.

Branching of the stem

Branching may be classified into 1. *Dichotomous* and 2. *Lateral.*

1. *Dichotomous branching:* The growth in length in plants takes place by means of the terminal bud. If the terminal bud divides into two and each one of them develops into two similar branches, it is called dichotomous branching. Such true dichotomous branching is rare in flowering plants.

2. *Lateral branching:* It is produced by development and growth of the axillary buds. Due to different degrees of branching the resulting growth may be monopodial or sympodial as follows.

(1) *Monopodial growth:* The main stem grows indefinitely by the activity of the terminal bud and gives off branches in *acropetal succession.* That is, older and longer branches are arranged at the base of the main axis and the younger and shorter branches are above, so as to give a conical appearance. e.g. *Casuarina* (Fig. 3.1).

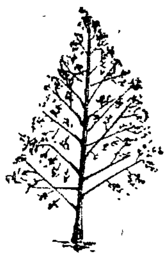

FIG. 3.1
Monopodial branching

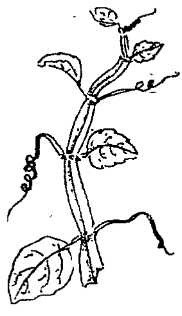

FIG. 3.2
Sympodial branching

(2) *Sympodial growth:* The terminal bud stops its growth after some years and further growth of the stem is continued by the axillary buds. e.g. *Cissus quadrangularis* (Fig. 3.2).

CLASSIFICATION OF STEMS

During the germination of the seed, the shoot system develops from the plumule of the embryo. In the majority of the plants, the stem is seen above ground. Such aerial stems are called *epigeous stems*. In some plants in addition to the epigeous stems, there are parts of stems found below the surface of the soil. They are described as *underground stems*.

Epigeous stems

Erect stemmed plants: The stems of these plants are generally strong enough to stand erect and support the branches. e.g., *Leucas aspera*, *Casuarina*.

Weak stemmed plants: In some plants, the aerial stem is thin, weak and hence unable to stand erect. The weak stems of such plants may creep along the ground or climb over the neighbouring supports.

1. Weak-stemmed horizontal plants

The stems of these plants horizontally along the soil. These may be further divided into the following types:

1. Prostrate.
2. Decumbent.
3. Runner.
4. Sucker.
5. Stolon.
6. Offset.

1. *Prostrate* The stems of these plants are weak, slender and long, which trail along the surface of the soil. As the plants usually lie flat they are called *procumbent*. e.g., *Tribulus terrestris*, *Evolvus alsinoides* (Fig. 3.3).

Fig. 3.3 Prostrate

Fig. 3.4 Decumbent

2. *Decumbent*. The stem is horizontal for some length but becomes erect at the tip e.g. *Tridax procumbens*, *Gomphrena decumbens* (Fig. 3.4).

3. *Runner:* There is a main stem fixed to the soil, with a number of leaves clustered together. Axillary buds grow out into long slender branches having long internodes. At each node, leaves arise on the upper side and adventitious roots from the lower sides of the node. Daughter plant capable of leading an independent life can develop from its mother plant. Such a slender horizontal branch giving rise to new plants at the nodes is called a runner. e.g., *Hydrocotyle asiatica*, *Oxalis corniculata* (Fig. 3.5).

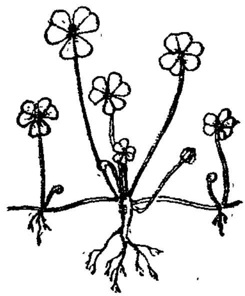

Fig. 3.5 Runner

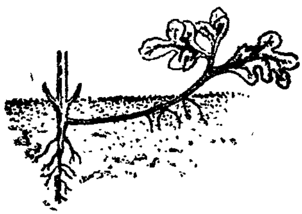

Fig. 3.6 Sucker

4. *Sucker:* Runners found beneath the soil are called suckers. They run horizontally for some distance, giving off adventitious roots at the nodes and finally grow upwards and comes out of the soil producing aerial shoots. Such underg round runners are called suckers. e.g., *Chrysanthemum* (Fig. 3.6).

Suckers may arise either from underground stems as in Mint or from roots as in Rose.

5. *Stolon*. Like the runner, this is also a slender axillary branch originating from the base of the stem. But at first, it grows obliquely upwards to some extent and then bends

down to the ground, striking adventitious buds and adventitious roots. This becomes a daughter plant. This may give rise to many such stolons, each provided with long or short inter nodes and spread in different directions e.g. *Fragaria indica* (Fig. 3.7).

FIG. 3.7 Stolon

6. *Offset:* Like runners, this originates in the axil of a leaf as a short, more or less thickened, horizontal branch. It elongates only to a certain extent and produces at the apex a tuft of leaves above and a cluster of roots below. The offset often

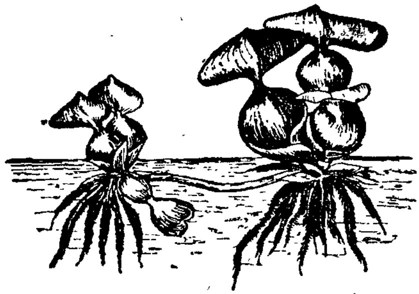

FIG. 3.8 Offset

breaks away from the mother plant, so as to lead an independent life. Thus an offset is shorter and stouter than a runner. e.g., *Pistia*, *Eichhornia*. (Fig. 3.8).

II. Climbing plants

These are weak stemmed plants which stand erect with the help of support. These are classified into three types.

A. Twiners.

B. Climbers.

C. Lianes.

A. TWINERS:

Twiners are weak stemmed plants which make use of their stems for climbimg by twining round a support. These twiners have slender stems with long internodes.

B. CLIMBERS:

The climbers are provided with special organs for climbing. They are given different names according to the nature of the climbing organ.

1. Tendril climbers.
2. Hook climbers.
3. Thorn stragglers.
4. Root climbers.

1. *Tendril climbers:* Tendrils are slender, spirally coiled spring like structures. They are highly sensitive to contact and when they come across any support they coil round the support. They represent different organs of the plant that are modified to help the plant in climbing.

(a) In *Cissus quadrangularis,* the terminal bud is modified into tendril (Fig. 3.9).

FIG. 3.9 Cissus quadrangularis

FIG. 3.10 Passiflora

FIG. 3.11 Lathyrus

(b) In *Passiflora,* the axillary bud is modified into tendril (Fig. 3.10).

(c) In *Lathyrus*, the entire leaf is modified into **tendril** (**Fig.** 3.11).

(d) In *Pisum sativum*, the terminal leaflets of a **compound leaf** are modified into tendrils (Fig. 3.12).

(e) *Clematis*, the petiole of the leaf is modified into **tendril** (**Fig.** 3.13).

(f) In *Smilax*, the stipules are modified into tendrils (**Fig.** 3.14).

FIG. 3.12
Pisum sativum

FIG. 3.13
Clematis

FIG. 3.14
Smilax

(g) In *Gloriosa superba*, the leaf tip is modified into **tendril** (**Fig.** 3.15).

(h) In *Antigonon leptopus* the tip of the peduncle **and the terminal** flowers are modified into tendrils (Fig. 3.16).

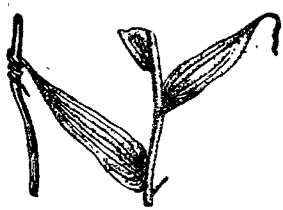

FIG. 3.15
Gloriosa superba

FIG. 3.16
Antigonon leptopus

2. *Hook-climbers:* In some plants strong and thick hooks are present. These hooks clasp the support firmly and thus enable the plants to climb up.

(a) In *Bauhinia variegata* the axillary bud is modified into hook (Fig. 3.17).

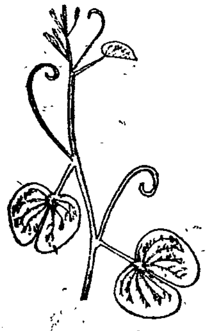

Fig. 3.17
Bauhinia variegata

Fig. 3.18
Artabotrys odoratissimus

(b) In *Artabotrys odoratissimus*, the peduncle is modified into a hook (Fig. 3.18).

3. *Thorn stragglers:* These plants have a number of thorns developed on the stem. These thorns are sharp and point downwards so that the stem clings to the support firmly. Thorns may be merely superficial structures developed all over the stem and are called emergences or prickles as in *Solanum trilobatum* and Rose. Or the thorns may represent normal plant organs modified for purpose of straggling as in the following examples:

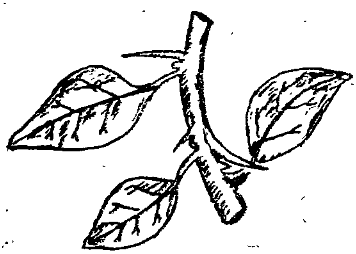

Fig 3 19 Bougainvillea spectablis

Fig. 3.20 Ziziphus jujuba

(a) In *Bougainvillea spectablis*, the axillary bud is modified into thorn (Fig. 3.19).

(b) In *Ziziphus jujuba* and *Capparis*, the stipules are modified into thorns (Fig. 3.20).

(c) In *Calamus rotang*, the basal leaflets of a compund leaf are modified into thorns (Fig. 3.21).

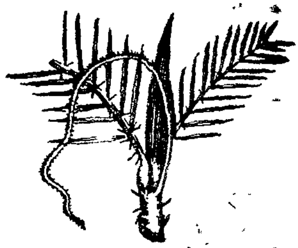

FIG. 3.21. Calamus rotang

4. *Root-climbers:* In pepper and betel vine aerial adventitious roots are developed at the nodes which are useful for climbing.

C. LIANES

In tropical rain forests, there are large woody twiners which grow to great heights. They are rooted in the soil, but twine around the support and reach the top of the trees. They may not have special climbing organs e.g. *Bauhinia vahlii*.

UNDERGROUND STEMS

In some plants underground stems perform certain special functions like storage, vegetative propagation and perennation.

The plants store their food materials in their underground stems.

Underground stems can store food materials.

The aerial portion of the stem dries up during the end of the growing season, while the underground stem stays alive to give rise to new plants on the advent of the favourable season. Thus the undergrounds tems are useful as organs of perennation and for vegetative propagation.

There are four important types of underground stems.

1. Rhizome.
2. Corm.
3. Tuber.
4. Bulb.

1. *Rhizome:* Rhizome is an underground main stem which grows more or less horizontally under the surface of the soil. Due to the storage of food materials, it is fleshy. It is divided into nodes and internodes and bears brown scale leaves at their nodes. In the axils of scale leaves, there are axillary buds. There is also a terminal bud found at the apex of the rhizome. From the lower surface of the rhizome there are many adventitious roots which fix it to the soil.

The terminal bud of the rhizome develops into aerial green shoot system with green leaves and flowers. At the end of the growing season the green aerial shoot system dies out and further growth of the rhizome is taken up by the axillary bud nearest the terminal bud. So the growth of the rhizome is said to be *sympodial* e.g., (Ginger) *Zingiber officinale*, (Turmeric) *Curcuma longa* and *Canna indica* (Fig. 3.22).

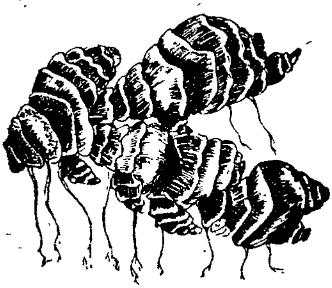

FIG. 3.22 Rhizome

2. *Corm:* Here the underground stem is not horizontal as in rhizome. This is also a main stem like rhizome. It is quite massive, swollen and slightly spherical due to the sortage of food materials. There fairly is a big terminal bud at the apex of the corm. There are also numerous scale leaves surrounding the terminal bud, each having a small bud in its axil. The corm is

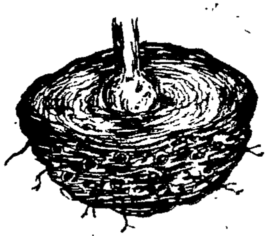

FIG. 3.23 Corm

attached to the soil by numerous adventitious roots. Under favourable conditions, the terminal bud develops into a green aerial shoot. e.g., *Amorphophallus campanulatus*, *Colocasia antiquorum* (Fig. 3.23).

3. *Tuber* This represents the swollen end of a branch. This arises from the axil of a leaf, grows horizontally and ultimately swells up at the apex. e.g., (Potato) *Solanum tuberosum*. In this, there are structures known as 'eyes'. Each eye represents a node with the scar of the scale leaf and a depression containing axillary bud. Under favourable conditions the buds in the eyes develop into aerial shoot system (Fig. 3.24).

FIG. 3.24 Tuber

4. *Bulb* The bulb consists of a much reduced stem, which may be conical or convex in shape. There is also a terminal bud covered over by a number of fleshy scale leaves. While the inner scale leaves are fleshy the outer ones are dry as in

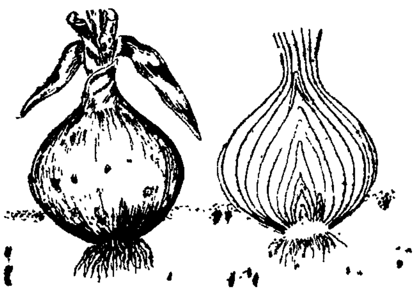

FIG. 3.25 Bulb

(Onion) *Allium cepa*. The scale leaves are arranged in concentric manner. So the bulb is described as tunicated (Fig. 3.25).

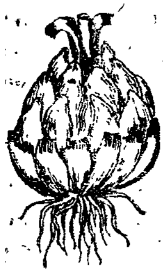

FIG. 3.26 Naked

In *Scilla*, the scale leaves are not arranged in a concentric manner as in Onion, but simply overlap one another by their edges. There are no dry scale leaves as in Onion. Such bulbs are described as *naked* (Fig. 3.26).

Aerial modifications of stem

The normal functions of stems are to give support and do conduction. In addition to these normal functions, stems may also perform certain special functions and for this they are variously modified.

Cladode: If the entire shoot system is modified to become a flattened green structure, doing the function of the leaf, it is known as a *phylloclade*. If it consists of one internode only it is described as a *cladode*. But many botanists treat both the terms as synonymous.

Phylloclades and cladodes are found in Xerophytic plants which grow in places where the available water is minimum combined with the increase in temperature and dryness. Plants found in such habitats conserve water and check excessive transpiration.

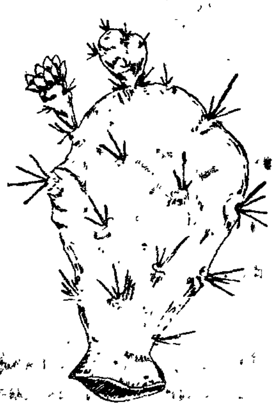

FIG. 3.27 Opuntia dillenii

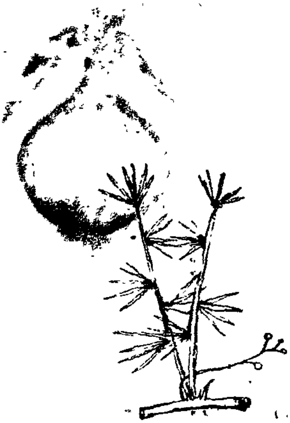

FIG. 3.28 Asparagus

Opuntia dillenii is a xerophyte. The shoot system consists of several segments which are flattened and green. They are fleshy storing large quantities of water. This contains a substance called mucilage which prevents desication. The flattened stem does the function of the leaf. The leaves are small and fall off early. There is a thick cuticle over the stem.

On the flattened stems, there are raised portions called *tubercles* where reduced leaves are present. There are a number of spines on the tubercle. The spine bearing area of the tubercle is called areole. Other examples are *Euphorbia antiquorum*, *Cereus*, *Muehlenbeckia* and (Fig. 3.27).

In *Asparagus* the cladodes are needle like and arise in clusters in the axil of a scale leaf. (Fig. 3.28).

ANATOMY OF THE STEM

From the anatomical standpoint the aerial axis of vascular plants possessing xylem and phloem as vascular tissues is known as the stem. The stem bears leaves and flowers. The stems may be simple, solitary without branches and short lived as in the case of many herbaceous annuals or woody bearing several branches, leaves and flowers and long lived as in trees and shrubs. In certain cases the stems become modified and remain underground in the form of bulbs *Allium cepa* (Onion), rhizome (*Zingiber officinale* - ginger), corm (*Amorphophallus campanulatus*-Yam) or branches modified in the form of tuber (*Solanum tuberosum*-Potato). However stems both normal and modified are marked by nodes and internodes, the former are recognized as the leaf bearing loci. The leaves usually develop buds in their axils known as the axillary buds. They may be active or remain dormant depending upon their physiological conditions. The whole stem together with its leaves represent the shoot system of a plant. The trees show sympodial or monopodial growth. In the sympodial growth the activity of the terminal buds is limited and further growth is assured and carried over by ateral or axillary buds. Under such circumstances the growth form ultimately results in a spreading type (*Ficus benghalensis*-

Banyan tree). In the case of the monopodial type of growth the terminal buds are more active and continuous than the lateral or axillary buds and thus finally giving rise to a tall cone like or pyramidal growth form (*Pinus strobus* -The Pine; *Cocos nucifera* -The coconut).

The stems just like the roots are constituted of three major tissue systems when considered in the broad sense namely the dermal, the fundamental and the fascicular or vascular systems. The variations in the primary structure of the stems of different species seem to be in the first place due to relative quantum and distribution of the fundamantal and vascular tissues. Some times such variations are further enhanced by the presence of certain types of idioblasts (special cells within a tissue markedly differing in form, size, structure and contents from the remainder of the same tissue), etc. In the dicotyledons the vascular system of an internode (nodes not considered here because of their different anatomical construction) when considered in its three dimensional aspect appears to be delimited externally by the non vascular tissues namely cortex and internally by pith. Thus the vascular system as such exists in the form of a hollow cylinder (Fig. 3.29; 8.12). The vascular system in the case of a dicotyledon may be continuous without any apparent subdivision and gaps in between or subdivided into certain number of discrete units being separated by gaps (regions occupied by non vascular tissues; Fig. 3.29; 8.12). Each one of the units is known as the vascular bundle or fascicle as seen in transverse sections. But when considered with reference to the axis as a whole, it is in the form of a vertical strand anastomosing with each other here and there throughout its course as observed in longitudinal aspect. The intervening area or gap (parenchymatous) between any two units is known as the interfascicular area and it is occupied by parenchyma (Fig. 8.12). This area is also often called the medullary or pith ray since it appears to radiate from the pith or medulla of a stem (Fig 3.29). On the other hand most of the monocotyledons reveal a more complex arrangement particularly with respect to the number and pattern of distribution of the vascular bundles. When observed in transections they do not usually appear in the form of a ring of vascular

bundles as in the case of a young dicotyledon stem but appear to be distributed throughout the transection of the stem. Because of this the usual distinction between the pith and cortex is lost or becomes less precise (Fig. 3.38). Although the pattern of arrangement (regular *versus* scattered) and the number of vascular bundles (limited *versus* unlimited) are usually said to be the marks of distinction between the stems of dicotyledons and those monocotyledons, these presumed criteria many a time fail and hence to be followed with caution (see elsewhere). Because there are a few dicotyledons showing the so-called monocotyledonous stem structure and *vice versa*. On the other hand, features such as the absence of a vascular cambium in the vascular bundles (closed condition) and the presence of bundle sheaths are characteristically seen in the stems of monocotyledons. Therefore, these features may be emphasized as contrasting with those of docotyledons and employed for the purpose of distinction.

The primary structure (young,) secondary structure (old) of the stem and the structure of the leaf of a dicotyledon plant are explained with the help of *Ricinus communis* L. (castor bean). The internal structure of stem and root of a monocotyledon plant is described with the help of a common grass, *Chloris barbata* Sw. (kodai pullu, sevarugu pullu).

Primary structure *Ricinus Communis* L. (transection of internode)-Fig. 3.29;3.31;

Diameter of the internode examined is 1.9. mm. *Cuticle* is rather thin and uniform in thickness and smooth. *Epidermis* consists of a single layer of cells which are somewhat radially elongated. The cells are compactly arranged without intercellular spaces. The epidermis remains intact in all the primary organs but during the process of secondary growth taking place in the concerned organs, it is replaced by secondary protective layers. *Hypodermis* consisting of 5-6 layers of collenchyma, the cells of which are characterized by thickenings at their corners and hence known as angular collenchyma (Fig. 2.25). Cells appear rounded in transections (Fig. 2.25). *Cortex* consists of about 6 layers of thin-walled parenchyma cells which are

variable in size and shape and arranged with intercellular spaces; most of them containing chloroplasts and hence called chlorenchyma. *Vascular bundles* 13 in number, discrete, separated by broad zone of interfascicular parenchyma and arranged in the form a single ring thus representing an eustelic condition. Vascular bundles varying in size, oval shaped, open because of the presence of vascular cambium which is single layered but apparently appearing more than 1-layered; the initials are radially narrow, thin-walled, slightly tangentially elongated and arranged more or less in regular tiers. *Primary Xylem* endarch, containing both protoxylem and metaxylem elements. Protoxylem elements being the first formed ones are characterized by annular or helical thickenings or both annular and helically thickned elements may be present (Fig. 8.9); the elements are narrow and considerably elongated and situated nearest to the centre of the axis; sometimes the very first formed elements of the protoxylem may become crushed thus giving rise to protoxylem lacuna (Fig 3.31). The metaxylem elements on the other hand being the later formed ones developed subsequent to the differentiation of the protoxylem elements and the organs concerned cease their elongation are characterized by thickenings which are in the form of scalariform and reticulate types (Fig. 8.9). Furthermore these elements unlike those of the protoxylem are broad and short. However both these elements are arranged in radial rows. The primary xylem elements are associated with parenchyma. *Primary phloem* contains protophloem and metaphloem. They are recognized just as in the case of primary xylem on the basis of time of appearance and sequence of differentiation. The protophloem elements develop and differentiate first as the organs undergo rapid elongation. Because of this situation the elements concerned are narrow and considerably elongated. With respect to the position, the protophloem elements occupy the outer limits of each vascular bundle. Furthermore the sieve areas are difficult to recognize because of the greater length of the elements (sieve tube members) and the companion cells and phloem parenchyma may be absent. They function only for a brief period and in the case of rapidly elongating organs, they are destroyed (obliteration) or differentiated into fibers. The sieve tube

members of the metaphloem on the other hand are broader and relatively short. Because they develop and differentiate after the cessation of the elongation of the organs concerned. Unlike the sieve tube members of the protophloem, those of the metaphloem are characterized by the presence of distinct sieve areas companion cells and phloem parenchyma. The metaphloem lack fibers and retain activity for a longer period. The metaphloem is nearest to the vascular cambium. The vascular bundles containing both primary phloem and xylem arranged on the same radius are called collateral bundles. They are characteristically seen in all the aerial organs. *Pith* is broad, parenchymatous the cells of which are thin-walled and arranged with intercellular spaces. *Idioblasts* are commonly present in the pith particularly in the cells adjoining the vascular bundles; secretory cavities of schizogenous origin (originating by separation of cell walls) being surrounded by a regular rosette of cells are common in the neighbourhood of primary phloem and sometimes in the pith.

Status of Endodermis and pericycle

The endodermis which is typical in the roots of dicots and monocots is wanting in the stems (compare Fig 3.29; 3.31 with 2.34; 2.45;). In a few cases an endodermis like layer is observed but it is nothing but a specialized layer containing starch. Therefore such a layer is known as starch sheath or endodermoid layer. Likewise the pericycle which is so characteristically present in the roots of both dicots and monocots is absent, in the stems. What appears as and is generally supposed to be a pericycle in certain stems is in reality nothing but a layer of fibrous cells. Secondly the pericycle of the roots is capable of becoming meristematic and giving rise to derivatives in the dicotyledons at the commencement of secondary growth. But the so-called pericycle of the stems consisting of a layer or layers of dead cells is incapable of giving rise to any derivatives. From the foregoing it may be concluded that the root pericycle is both structurally and functionally different from the so-called stem pericycle.

Secondary structure

The stems and roots of dicotyledonous trees and shrubs during and after undergoing secondary growth and changes (mechanism of secondary growth, see below) develop secondary tissues. They in course of time replace all the primary tissues. The secondary tissues are represented in the form of secondary xylem (also known as wood in non technical sense), secondary phloem, periderm consisting of phellogen (cork cambium), phellem (cork) and phelloderm (secondary cortex). All these secondary tissues as mentioned earlier are produced by secondary meristems namely vascular cambium and phellogen. Out of these scondary tissues, it may be observed in any woody dicotyledonous stems and roots, that the secondary xylem because of its over production and over representation forms the major bulk of the secondary body.. Furthermore the secondary xylem of several years of growth and development particularly that of the stems is the ultimate source for all economically important timbers. Secondary xylem is the compactly arranged woody and dead tissues which are mainly responsible for causing the woodiness in plants. The secondary xylem being a complex tissue consists of vessels, fibers, axial parenchyma. Because of their vertical arrangement they represent the axial, vertical or longitudinal system of secondary xylem (Fig 3.47). These different tissues are formed by the fusiform initials of the vascular cambium. In contrast to this, the horizontal, radial or transverse system of the secondary xylem is represented by ray parenchyma. This is organized by the activity of the ray initials of the vascular cambium. Thus, it is interesting to observe in any given secondary xylem, the existence of the above mentioned two systems resemble the warp and woof pattern (Fig 3.47). Likewise these two systems of arrangement of secondary tissues are also encountered within the secondary phloem also. The vertical system of the secondary phloem comprises the sieve tubes and their associated companion cells, phloem parenchyma, and phloem fibers. The horizontal system is represented by the ray parenchyma. However all the components of the secondary phloem are derived from the fusiform and ray initials of the vascular cambium. One noteworthy difference between secondary xylem and secondary

phloem despite their common origin is that the latter is produced in lesser amount. Secondly the one formed in the previous season is replaced and replenished by the secondary phloem formed during the current season. In other words, the production of secondary phloem is periodical and seasonal. It is not accumulated as observed in the case of secondary xylem.

Mechanism of secondary growth

As mentioned earlier the vascular bundles of dicotyledon stems are open as they are containg a meristem now known as the vascular cambium (since concerned with the production of vascular tissues) or fascicular cambium (since it is present within a fascicle or bundle;) (Fig 3.29; 3.31). The vascular cambium originates from a primary meristem known as the procambium. The moment the vascular cambium starts dividing periclinally, the initiation of secondary growth is considered to set in. By such divisions derivatives are formed both towards the side of the primary xylem and primary phloem. Thus the production of the derivatives becomes bidirectional. It is interesting to know that the division activity of the initials of the vascular cambium is not always restricted to only one side but it is bilateral. Because every time the initials divide periclinally, one of the daughter cells falling either on the xylem side or on the phloem side becomes the xylem or phloem mother cell as the case may be, while the other one functions as the true initial. But at the same time it should not be imagined that there is a regular alternation of this phenomenon. In fact, in any species the number of divisions on the xylem side is more than those that are taking place on the phloem side (4:1 as reported in species of *Eucalyptus*). The immediately formed derivatives do not differentiate directly into the respective components of secondary xylem and secondary phloem. Instead, they in their turn undergo few divisions just as the initials proper. Therefore they are known as the xylem and phloem mother cells. Only the ultimate division products of xylem and phloem mother cells differentiate into various components of secondary xylem and secondary phloem. Thus in the place of the original single layer of fascicular cambial initials dividing

periclinally it is now seen that it is bordered on either side by a few more or less similar layers of periclinally dividing xylem and phloem mother cells. Under this situation it is better to consider this zone as the 'cambial zone' (Fig.3.33; 3.41). This situation warrants the necessity of maintaining a dual concept regarding the status of the vascular cambium; one for theoretical purpose and the other for practical purpose. During the quiescent or non functioning stage, the vascular cambium represents a single layer of initials (fusiform and ray initials) which holds good for theoretical considerations. But during its functioning or active stage it reflects a multilayered organization, revealing not only the original initials proper but the dividing xylem and phloem mother cells also.

The parenchyma present in between the vascular bundles known as the interfascicular parenchyma also becomes meristematic in the mean time and starts dividing periclinally. The cells adjoining the vascular bundles commence this activity first (Fig 3.33). In course of time the wave of meristematic activity initiated in the interfascicular parenchyma lying next to the vascular bundles extends laterally. Finally the interfascicular area is bridged by a meristematic layer of cells. This meristematic layer which is thus differentiated together with the fascicular or vascular cambium already present in the vascular bundles unite with each other. This union results in the formation of a continuous cambial ring(Fig 3.32). This cambial layer now becomes the active centre for the production of derivatives. They are differentiating into the various components of the secondary xylem towards inside and secondary phloem towards outside. As the periclinal divisions are taking place in the initials and mother cells (initials here refer to the fusiform and ray initials and the cells to xylem and phloem mother cells) of the cambial zone the initials themselves (sometimes the xylem and phloem mother cells also) enter into another type of division from time to time. It is known as the radial divisions (Fig. 2.22). These radial divisions are equally important since they meet the demand for the multiplication of the initials (sometimes the xylem and phloem mother cells) which are necessary to cause the increase in the girth of the cambial zone and to enable it to keep pace with the expanding axis. The phenomenon of radial division is one of the means to achieve this end.

These two kinds of dual activity (one responsible for the formation of derivatives through periclinal division and another for the multiplication of the initials themselves through radial divisions) continue depending upon the seasonal, physiological factors etc.

Mechanism of Secondary Growth in Non Vascular Region—Periderm Formation

The mechanism of secondary growth explained above pertains only to the vascular regions of the axis. As the secondary growth and changes are taking place other kinds of secondary changes are also initiated in the non vascular regions (epidermis, hypodermis and cortex) by another type of mechanism. In this mechanism another kind of meristem known as the phellogen or cork cambium is involved. The phellogen by its activity organizes periderm. The periderm is a complex tissue since it represents phellem or cork outside and phelloderm or secondary cortex inside. The periderm particularly the phellem part of it becomes the outer effective protective layer for the axes (sing. axis) undergoing increase in the girth.

The phellogen cells appear rectangular in transection and more or less flattened radially (Fig. 3.42). They divide periclinally and the products of division are added on either side of the phellogen. In this respect, the phellogen resembles the vascular cambium. The phellogen develops either directly from the epidermis or from the hypodermis or from any layers of the cortex. As far as *Ricinus communis* is concerned the phellogen differentiates directly from the epidermis itself thus becoming superficial in origin. The derivatives formed external to the phellogen differentiate into a special type of tissue known as the phellom or cork Fig (8.11) and those that are added internal to the phellogen become the phelloderm or secondary cortex (Fig. 3.40;3.42). The phellogen together with its derivatives namely outer phellem and inner phelloderm comprise what is known as the periderm (Fig. 3.42). The periderm formation in the manner described above may sometimes take place even when the stems are young (precocious) or coincide approximately with the commencement of

secondary growth in the vascular regions (synchronous) or sometimes very late (belated). In this respect *Ricinus communis* belongs to the latter category.

The phellem of cork cells are compactly arranged without intercellular spaces and in regular radial rows (Fig. 8.11). They are somewhat tangentially elongated or flattened and radially narrow (Fig. 8.11). The cell walls are deposited with alternating layers of suberin and wax. When fully differentiated the cells become dead. The cork layers are also impervious to water and air. All the above mentioned characteristics of the cork cells qualify them to function as efficient protective tissue. It is interesting to know that because of these structural characteristics and functional efficiency the bottle cork and other kinds of corky insulating materials are obtained from phellem produced by *Quercus suber* (cork plant). Sometimes the periderm is erroneously considered synonymous with the non technical term bark. But bark implies not only the periderm but all other *secondary tissues lying outside* the vascular cambium. On the other hand, in the case of arborescent monocotyledons such as Palms there is no periderm formation in the *manner explained above*, but *instead* the epidermis and/or the subjacent ground tissues undergo suberization or thickening or sclerification followed by the multiplication of the *existing cells. Thus the protective* tissues are built up by them.

Lenticels: Lenticles are small lens shaped, oval, elliptical, rounded or vertically linear areas (Fig. 3.30) associated with and distributed over the periderm. They usually appear as elevated pustules and as such they are visible to the naked eye (Fig. 3.30). Their formation is necessary in order to favour the gaseous exchange which is otherwise denied to the tissues within because of the development of tight protective impervious phellem layers outside. In fact the lenticels when examined under the microscope represent small openings but filled with loosely arranged parenchyma cells known as complementary or filling cells (Fig. 8.10). The lenticels are abundantly seen particularly in the older parts of the stems and roots of dicotyledonous plants. They are formed by a separate

meristem called lenticel phellogen. This arises usually out of the subjacent parenchyma cells lying just beneath the stomata and sometimes from other regions as well. In certain examples it is also interesting to observe the occurrence of lenticels right opposite the rays.

Secondary Structure—*Ricinus communis* L. (transection)—Fig. 3.40; 3.41).

For the sake of convenience the structure of the stem undergoing secondary growth is described here under two stages (early stage—I and late stage—II) as follows:

Stage I: The diameter of the stem examined under this early stage or soon after the initiation of secondary growth is about 3 mm. At this stage all the anatomical characteristics of the primary axis (young internode described above) are observed except the following differences. 1. There is a formation and establishment of a continuous cambial zone as described above. 2. Adjoining the cambial zone few vessels and xylem fibers are being formed internally representing the secondary xylem and likewise externally secondary phloem with broad sieve tube element and companion cells are differentiating. 3. At the outer limits of secondary phloem sclereids are already differentiated out of the primary phloem components undergoing obliteration. These sclereids occur in an isolated manner. 4. The solid pith now becomes hollow due to the disorganization of pith parenchyma.

Stage II: Diameter of the stem examined under this late stage or after sufficient amount of secondary growth has taken place is about 1.4 cm. Under this stage it is quite clearly observed that there is a total replacement of all primary tissues except the primary xylem, by the secondary tissues produced by the activity of the vascular cambium and phellogen. The following anatomical changes in terms of secondary tissues and their respective characteristics are noticed. 1. The number of layers in hypodermal collenchyma becomes almost doubled (15 layers). 2. The number of layers in cortical chlorenchyma becomes almost halved (3 layers). 3. Instead of sclereids

occurring in isolated manner as seen in the stage I, nests of sclereids are differentiated at the outer limits of the secondary phloem of the previous season. 4. Continuous development of secondary phloem is observed but it is separated by phloem rays; groups of phloem fibers are developed within the secondary phloem of the current year; sieve tube elements of the secondary phloem are broad. 5. Vascular cambial zone appears rather broad consisting of dividing initials and mother cells. 6. Several layers of secondary xylem are formed comprising compact woody tissues namely vessels and fibers and non woody tissue xylem or axial parenchyma. The vessels appear in transection in the form of circular or oval pores. They are distributed in radial multiples of 2-3 and sometimes solitary. Rays run across radially in the form of thin lines right through the secondary xylem. The xylem fibers appear angular in outline, thick-walled and arranged without intercellular spaces. The xylem or axial parenchyma is present in a diffuse manner. Abutting on the pith the original primary xylem remains intact. 7. The origin of the phellogen is superficial since it directly originates from the epidermis. The phelloderm consists of several layers of cells which are large, tangentially elongated. The cells possess pits which are elongated, reticulate or scalariform (Fig. 3.42). Some of the cells contain chloroplasts. Nests of sclereids and druses are very common in the phelloderm. Cubical crystals are sometimes observed. The phellem consists of 4-6 layers of tangentially flattened thick-walled, narrow cells. They are arranged almost in regular tiers. Intercellular spaces are absent in them. 8. Lenticels are abundantly developed on the surface of the periderm. They appear linear and elongated. As a result of the formation of lenticels the outermost layer of cells becomes ruptured every time and remain in frayed condition as more and more parenchyma cells are produced from within by the lenticel phellogen.

Growth Layers. If the woody part or secondary xylem of the trunk or of the root of any suitable example is sawn across and the exposed surface is polished several concentric rings within the secondary xylem become easily visible even to the unaided eyes. These are known as the growth layers or growth rings

(Fig. 3.45). The formation of such rings indicates indirectly the periodic activity of the vascular cambium and the consequent increments of derivatives; that is to say the cambial activity is more vigorous during the formation of secondary xylem at the commencement of each ring and gradually tapering towards the end and finally its activity comes to a standstill. In the next following season the activity is once again triggered as explained above. Thus this phenomenon seems to be periodical and recurring. In other words, these growth layers may be considered as the blue print reflecting the alternate functioning and non-functioning phases of and any adverse effects if any on the vascualr cambium. Each growth layer represents the increment of secondary xylem produced during one season. The growth layer formation is quite a characteristic feature of woody species growing in temperate zones where the extremes of climatic conditions prevail markedly. Within each growth layer the secondary xylem or wood, two kinds of wood are recognizable. One kind of wood is known as the early wood and the other as the late wood (Fig. 3.43; 3.44; 3.45). The early wood is characterized by cells and vessels which are broader and less dense than those of the late wood. Furthermore the early wood is so called because it is formed during early part of the season while the late wood is the one that is produced towards the end of the season. In the temperate zone since the early wood formation is associated with spring it is also known as the 'spring wood'. Likewise the production of late wood is correlated with summer and it is labelled as 'summer wood' (Fig. 3.43; 3.44; 3.45). Similarly quite a number of other terms are available to refer to the two kinds of wood of a growth layer. Among them two recently proposed and recommended terms namely 'light wood' and 'dense wood' appear to be the most appropriate ones (Fig. 3.43; 3.44; 3.45), because they connote two important characteristics of the wood such as weight and colour. The spring wood is lighter in weight and colour when compared with the summer wood which is dense in colour and weight. Under normal conditions when the formation of secondary xylem is regular and developing once during every season the growth layer or ring is also called annual layer or annual ring (Fig. 3.43; 3.44; 3.45). If the

successively produced growth layers are the products formed under uniformly regular alternation of spring and summer conditions each growth ring is counted as equivalent to one year Thus it is possible to estimate the age of a tree subtracting the periods of the seedling and of the primary growth, by counting the total number of such growth rings. In other words the number of growth rings is directly proportional to and agrees with the age of the tree. Another interesting aspect and application of the growth rings is that they are considered as useful indicators to find out the year or years in which forest fires or any other environmental catastrophes broke out. Because the growth rings formed under such abnormal conditions may be either false or incomplete or multiple. Therefore from the presence of such false, incomplete or multiple rings not only the catastrophes but the year of their happenings can be read out provided the year of planting of the species is known. Thus they are useful as chronicle.

The formation of growth rings need not be considered here as it is the characteristic feature of the temperate species alone. Sometimes the species growing under and exposed to spring and summer conditions of the climate elsewhere also do develop such growth rings. (*Tectona grandis* L. *f.*—teak plant).

Sap wood and Heart wood: With the continuous increments of secondary xylem and with the increasing age of the trees the earlier formed tissues gradually and progressively begin losing their original function of conduction of water. Thus they become totally non-functioning in this particular respect. But at the same time they are useful in affording resistance, durability and mechanical strength to the species. Taking into consideration the central position of such changing early part of the secondary xylem it is called the heart wood. On the contrary, still normally functioning and unaffected peripheral portion of the secondary xylem is known as the sap wood (Fig 3.45). The transformation of normally functioning wood into heart wood is preceded by and due to several chemical changes. Along with chemical changes, certain structural changes also take place. One such structural change is evident by the formation of tyloses (sing. tylose or tylosis) (Fig. 3.46) These

are nothing but the extension and subsequent distension of the cell wall of the adjoining parenchyma cell through the pits of the vessels. The tyloses by their occurrence right within the lumen of the vessel block the conduit. They are thus becoming responsible for the non functioning condition of the vessesls in the heart wood. The heart wood differs from the sap wood the former being infiltrated with several kinds of chemical compounds such as oils, tannins, resins, aromatic substances, pigments, crystals, the development of tyloses and certain other changes in the cell walls. Furthermore the heart wood may be distinguished by different colour which may be black, red, brown or green (*Diospyros* species).

Differences between young and old dicot stems: In any young dicot stems all the tissues are of primary origin. They originate from the primary meristems with the result no woodiness is produced in them. Consequent upon the secondary growth and changes caused by vascular cambium and phellogen (secondary meristems) all the primary tissues such as epidermis, cortex, vascular bundles containing primary xylem and phloem and pith are either replaced or crushed by the secondary tissues which are formed anew. For example, in the place of epidermis and cortex periderm is formed, lenticels are developed usually in the place of stomata, individuality of the vascular bundles is lost, primary phloem is crushed or part of it is modified into fibers or sclereids, primary xylem is retained in its original position near the pith, recurrent development of secondary phloem between the previously formed secondary phloem (previous season) and the functioning vascular cambium, continuous formation of secondary xylem (wood) between the primary xylem and the functioning vascular cambium, development of xylem and phloem rays, differentiation of wood into heart wood and sap wood, development of growth layers or rings containing light and dense woods. With all the above mentioned changes in the tissues and tissue systems the outward manifestation is also changed and seen ultimately in terms of increase in the girth of the stems and woodiness.

Differences between young stems and roots. Cuticle is present over the epidermis of the stems and it is wanting in that of roots.

The typical endodermis and pericycle are absent in stems but present in roots. The xylem and phloem of stems are arranged in the same radius thus becoming collateral with endarch xylem but in roots they are spatially separated and aligned in different alternating radii with exarch xylem. Stomata and different kinds of epidermal hairs which are usually present in stems are lacking in roots but instead unicellular root hairs are present in the latter (Compare Figs. 2.33; 2.34; 2.44; 2.45; with 3.29; 3.31; 3.38; 3.39).

Structure of a Monocot Stem (Culum)—*Chloris barbata* Sw.—(Fig. 3.38; 3.39)

Diameter of the culm described is about 2.7 mm. The outline of the culm in transection appears to be somewhat circular or oval shaped. Cuticle is rather thin and uniform throughout. *Epidermis:* cells are isodiametric and possess thick walls. *Hypodermis* consists of 10-12 continuous layers of sclerenchyma but interrupted by several sclerenchyma strands and islands of assimilatory tissues (chlorenchyma). Each one of the assimilatory tissues consists of fairly large cells filled with starch grains and chlorenchyma cells. Sclerenchyma strands triangular shaped. *Ground tissue* is represented by parenchyma the cells of which progressively become larger towards the centre and are arranged with intercellular spaces. *Vascular bundles* are 33-35 in number and are distributed peripherally in an irregular manner. In addition to these large bundles, several smaller bundles are embedded in the hypodermal sclerenchyma. These smaller vascular bundles are not only circular in outline but arranged to form a regular ring and in contrast to this situation the large bundles are usually oval shaped and distributed in an irregular manner. However each vascular bundle is collateral with endarch xylem and represents the closed type. All the vascular bundles are surrounded completely by 1-2 layers of sclerenchyma known as the circumvascular sclerenchyma. The number of metaxylem vessel elements per vascular bundle varies from 2-3 and arranged more or less in a transverse line. Protoxylem lacuna is usually present in all large vascular bundles. Metaphloem is characterized by fairly large sieve tube elements and each one of them is leterally associated with a companion cell.

Differences between young Dicot and Monocot stems: Many differences are usually listed out as marks of distinction between young dicot and monocot stems which in fact may not hold water. Because most of them originate from the cursory examination of just a few examples. Such presumed differences will easily break down if larger number of examples belonging to these two groups are surveyed for this purpose and in this respect it may be mentioned that for every character of distinction exceptions are always seen. After elimination of so called distinguishing characteristics, the only fundamental and dependable distinction that stands out is the presence of cambium in the vascular bundles of the dicotyledons and its absence in those of the monocotyledons.

PHYSIOLOGY OF THE SHOOT SYSTEM

Functions

The functions of the stem are support, translocation, storage propagation.

I. Support

The chief function of the stem is to support the leaves and flowers.

II. Translocation

The stem conducts water and mineral salts upward absolutely by root system and the food manufactured in the leaves downward to regions of demand and storage. This process by which water and food move through the plant is termed conduction or translocation.

The water containing mineral salts absorbed from the soil by the roots is known as sap. The sap is conducted upwards to the leaves, the growing regions of the stem and the branches. In herbaceous plants, the height to which this

water has to reach is small. Some trees like Australian *Eucalyptus*, *Sequoia* and some Conifers attain a height of 100 metres or more. In these the sap has to be lifted to a great height. The upward movement of water and dissolved substances is called the ascent of sap.

Path of movement of sap

The sap ascends in the plant through the xylem. This can be demonstrated by a simple experiment.

A small herbaceous plant namely Balsam is carefully uprooted and its root is kept immersed in a bottle containing water coloured with eosin. After sometime streaks of red colour will be seen along the whole length of the stem and also in the veins of leaves. If cross and longitudinal sections of the stem at different levels are taken and examined under the microscope, it is found that only xylem part is stained by eosin. This shows clearly that ascent of sap takes place only through the xylem vessels. (Fig. 3.48).

Fig. 3.48
Experiment to demonstrate the path of sap
1. Balsam plant
2. Eosin solution

Another experiment known as Ringing or Girdling experiment also proves that the ascent of sap takes place only through xylem. Two plants are taken. In one plant, all the tissues external to the xylem for a distance of about an inch are removed in the form of a ring (or girdling) from a branch without injuring the xylem. In another plant the continuity of xylem tissue is broken by making two opposite half cuts a short distance apart in a branch. In the former case, the leaves remain fresh and do not wilt. In the latter case, the leaves

wilt in a short time. Thus the removal of a ring of tissue external to the xylem does not interfere with upward movement of water but the break in the continuity of xylem stops

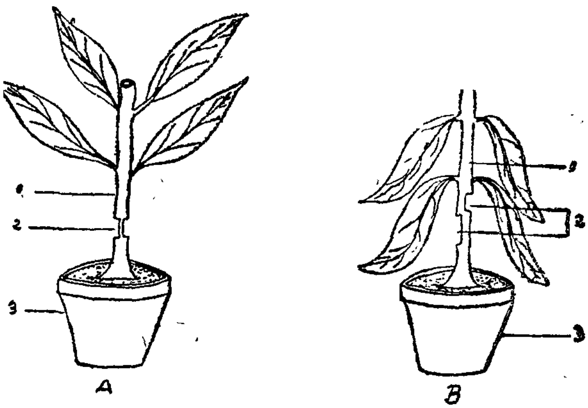

FIG. 3.49 Girdling or Ring experiment
A 1. plant 2. All the tissues external to xylem removed 3. Pot
B 1. Plant 2. Continuity of xylem interrupted 3. Pot

conduction of sap. This shows that the ascent of sap takes place through xylem. (Fig. 3.49).

Theories of Ascent of sap

Various theories have been put forward to explain the forces (factors) responsible for the ascent of sap. These are divided into vital theories and physical theories.

Vital Theories

These theories were proposed by Godlewski and others. They believed that the upward movement of water was due to the pumping activity of living cells of the stem, particularly ray and wood parenchyma cells. But these theories have not been accepted because water continues to rise in plants even after their living cells are killed.

Physical Theories

1. *Root pressure*. Root pressure may be adequate to force water in herbs, shrubs and small trees. The maximum root pressure does ot normally exceed 2 atmospheric pressures and hence it can raise the sap only upto 20 metres.

2. *Capillarity:* The phenomenon of the ascent of liquid within a tube of very small internal diameter is known as capillarity. It was thought that water may rise through the small bore of the xylem vessels by capillarity. The smaller the bore of the tube, the higher will be the rise of water in it. Accordingly one would expect that the tallest trees would possess vessels of narrowest bore but the reverse is often found to be the case. Therefore capillarity cannot account for the rise of sap beyond a few feet at the most.

3. *Imbibition theory:* Sachs believed that water rises up in the walls of the xylem vessels by imbibition. It has now been proved conclusively by experiments that translocation of water takes place through the cavity or lumen of the xylem vessels.

4. *Atmospheric pressure:* Atmospheric pressure can raise the water up only to a height of only 10 metres and it is not enough to raise the water in tall trees where a height of more than 100 metres has to be reached.

5. *Transpiration pull and cohesion theory:* This theory was put forward by Dixon and Jolly. According to this theory, sap is pulled up through the xylem vessels by the evaporation of water from the leaves during transpiration. The water column in the xylem vessels does not act as an ordinary column of liquid but rather as a solid column on account of the cohesive property of water molecules. The water molecules cohere so strongly that the column does not break and form air bubbles even under a state of tension due to transpiration pull. The cohesive power of water column is about 158 atmospheric pressures and this is capable of raising water to a height of about 1580 metres. There is no tree as high as that and therefore the cohesive force is considered as sufficiently powerful

to lift water in plants. When transpiration takes place, an upward pull is exerted from the upper end and the whole water column without any gap is pulled up like a rope. So this theory satisfactorily explains the force responsible for the ascent of sap.

Translocation of solutes

The movement of food materials (organic and inorganic solutes) from one part of a plant to another is known as translocation. It takes place in all directions.

Path of translocation of solutes

Translocation of food materials or solutes takes place through phloem. This can be proved by Ringing or Girdling experiment.

A ring of phloem encircling a stem is completely removed. After some days swellings appear just above the ring or girdle due to the accumulation of food which are halted by the interruption of phloem. This proves that phloem is primarily responsible for the translocation of food.

Chemical analysis of phloem sap shows the presence of a greater variety of food materials.

Mechanism of translocation of solutes

Various theories have been advanced to explain the mechanism of translocation of solutes in the phloem tissues. But none of them is quite satisfactory. They are:

1. *Streaming of protoplasm theory:* This theory states that the organic solutes are translocated from one end to the other end of a sieve tube by streaming movement of the protoplasm. The particles then diffuse from one sieve tube to the next by diffusion, through the cytoplasmic strands in the sieve plates.

Objections:

1. The rate of the streaming is too slow to account for the observed rates of translocation of foods.

2. This streaming movement of protoplasm is of rare occurrence in mature sieve tube.

2. *Diffusion hypothesis:* According to this hypothesis, translocation of food takes place from regions of higher concentration of solutes to the regions of lower concentration of solutes. Therefore different solutes may be moving simultaneously in opposite directions.

Objection

Simple diffusion cannot account for the observed rate of translocation in phloem.

3. *Munch Mass Flow (Pressure Flow) hypothesis:* According to this hypothesis, the higher turgor pressure of the leaf cells causes a mass flow of solutes downward in the phloem towards the roots. The flow from one cell to another is probably facilitated by the strands in the communicating pores and so the entire system acts as a unit.

The proposed mechanism is based on sound physical principles. It is observed that when phloem is cut, the exudate flows considerably. The virus transport through the phloem also supports this view.

Objections

1. There is frequent development of lower turgor pressure in the supplying cells.

2. Bidirectional movements of solutes in phloem have been observed.

III. Storage

The stem frequently serves as an important storage organ. It may become modified for food manufacture, water storage etc. Many plants manufacture more food than what is made. A large part of this surplus is stored in the stem. A stem is a better storage organ than an ordinary leaf as the former is usually a more permanent structure. Moreover it is of advant-

age to the plant that the surplus food manufactured in the leaves is removed from them so that food material does not accumulate and interfere with its continued production.

IV. Propagation

Plants have developed certain ways by which they can propagate themselves for the continuation of their race. Sub-aerial stems like runner and underground stems like rhizome, tuber etc. propagate vegetatively. The underground stems are provided with buds. These buds are capable of quick and vigorous growth by using the stored up food materials. New individuals can also be artificially produced through layering, cutting and grafting.

ECONOMIC IMPORTANCE OF STEMS

From very early times man has been using the stems of many plants in various ways. In fact he is being called a 'civilized man' only after he made use of many economically important plant products.

I. Food

Many of the underground stems and some of the aerial stems of herbaceous plants are used as vegetables.

1. *Solanum tuberosum* (*Potato*) (*Solanaceae*): Potato is one of the most important food plants of the world. It is a native of America and is cultivated widely in India.

The plant is an annual herb with underground tubers. It contains 18% carbohydrates 78% water 2% proteins and only 1% of fat. It is also used in the preparation of starch and alcoholic bevarages.

2. *Colocasia esculenta* (*Araceae*): This is a perennial herb which is cultivated in warm humid regions of our country. It contains carbohydrates, proteins some minerals like calcium, phosphorus and a few vitamins. It is used as a vegetable.

Its flour is used in making breads, biscuits and soups. Industrial alcohol is prepared after fermentation.

3. *Allium cepa and Allium sativum* (*Liliaceae*) : Both are bulbous biennial herbs cultivated largely in India. Both contain carbohydrates, proteins, calcium, phosphorus, Iron and vitamins A, B and C.

II. Saccharum officinarum (Graminea) (Sugarcane)

Sugarcane is cultivated in India since prehistoric times. The plant grows best in moist hot and sunny places with an average rainfall of 50 to 60 inches per annum and an optimum temperature of 75 to 80°F. It can best be grown in loamy soil with sufficient mineral matter.

It contains glucose, sucrose, proteins, organic acids, pectins and vitamins. The sugarcane breeding station in Coimbatore has evolved many new varieties of sugarcane which are cultivated throughout the world.

III. Rubber

There are many rubber yielding plants out of which *Hevea braziliansis*-Euphorbiaceae) is very important. It is a native of South America successfully introduced in India. The plant is a tall evergreen tree growing to a height of 60 to 150 feet and will live for 200 years. It is grown well in well drained loamy soil with an annual rainfall of 80 to 120 inches and 75 to 90° F.

Shallow incisions are made in the bark of the tree and the latex is collected and purified.

India rubber is obtained from *Ficus elastica* of Moraceae. But this is of inferior quality.

Rubber is used in making tyres, tubes of cycles, motor cycles and cars. It is also used to make shoes, belts, toys, cushions, gloves, waterproof clothes etc.

IV. Timber

Timber is obtained from large trees and it is variously used.

(a) In building houses, for pillars, doors and windows the timber used is obtained from *Tectona grandis*, (Teak) *Dalbergia latifolia* (Rosewood) *Mangifera indica* (Mango tree) etc.

(b) Furniture and almirahs are made from *Cedrela toona*, *Albizia lebbeck* etc.

(c) Agricultural implements are made from *Thespesia populnea*, *Acacia catechu* etc.

(d) Toys for children are made from *Morinda tinctoria*, *Santalum album* etc.

(e) Wooden sleepers for railways are obtained from *Xylia xylocarpa* and *Mesua ferea.*

(f) The wood of *Bombax malabaricum* and *Heretiera tarretia* are used to build boats.

(g) The wood of *Ailanthus malabaricum* and *Bombax malabaricum* are used in the preparation of matches.

(h) The musical instruments like Veena, Mirudhangam and Kanjira are made from (Jack) *Artocarpus integrifolia* and *Cedrela toona.*

V. Fibres

(a) Linen cloth is prepared from the fibres obtained from the stem of *Linun usitatissimum.*

(b) Artificial fibres like rayon and viscose for cloth making are obtained from the timbers of *Eucalyptus*, *Abies* etc.

(c) Fibres obtained from *Corchorus capsularis* and *Corchorus olitorius* are used to make the jute. Fibres are also obtained from *Hibiscus cannabinus* and *Cannabis sativa.* These fibres are useful in many ways.

VI. Medicine

The stems of many plants are useful in the preparation of many allopathic and indigenous medicines.

(a) From *Chenopodium umbrosioides* medicine is prepared to remove the worms from the alimentary canal.

(*b*) From the bark of *Cinchona officinalis*, quinine is obtained and it is given for Malaria fever.

(*c*) Medicines prepared from *Strychnos nux-vomica* are useful as a muscular relaxtant and to remove the hypertension of the nervous system.

VII. Tannin

Tannin is a substance which is very useful in the leather technology. It is an organic compound with many Glucosoides. It is obtained from many plants such as *Acacia arabica*, *Acacia dealbata*, *Cassia auriculata*, *Rhizophora mucronata*.

VIII. Dyes

Natural dyes are obtained from several plants.

(*a*) *Acacia catechu*, *Acacia arabica*, *Ventilago maderaspatana* give dyes useful for cotton and woollen fabrics.

(*b*) The yellow dye obtained from *Curcuma longa* and red dyes obtained from *Pterocarpus santalinus*, *Erythrina indica*, *Mallotus phillippinensis* are used to colour the medicines, cloth, footwear etc.

(*c*) The red dye obtained from *Ceasalpinia braziliensis* is useful in the preparation of red ink.

Rubber is obtained mainly from the stem of *Hevea brasiliensis* and also from a few other plants like *Manihot glaziovii* etc.

Paper is manufactured from plants including *Bambusa arundinacea* and *Ochlandra travancorica*.

Sandal wood oil is obtained from the wood of *Satalum album* which is useful in the preparation of soaps and perfumes.

THE SHOOT SYSTEM

B. THE LEAF

MORPHOLOGY

The leaf is regarded as the flattened, lateral outgrowth of the stem or the branch. It develops from the superficial tissues of a node (exogenously) and has a bud in its axil. In this respect, the leaf is regarded as a partial stem or branch, having a limited growth. Leaves develop in an acropetal order on the stem. They are normally green in colour and are the most conspicuous organs of a plant.

Functions of the leaf

1. *Photosynthesis:* The structure of the leaf is such that it is very well exposed to the sunlight and atmospheric air. With the help of the green coloured pigments present in the leaf, water, carbon dioxide and sunlight, leaf is able to synthesize its own food material and the process is known as Photosynthesis.

2. *Respiration:* There are small openings found on the *epidermis* of the leaves called *stomata*, through which exchange of gases take place. During respiration, oxygen is taken in and carbon dioxide is given off. This is done by all living cells and is said to be a *vital phenomenon.* During photosynthesis, carbon dioxide is taken in and oxygen is given off.

3. *Transpiration.* Plants absorb more water than is required. So the excess water is evaporated through the stomata in the form of water vapour. This process indirectly helps the plant in the absorption of water and mineral salts.

In addition to the above mentioned important functions, some of the leaves also do certain other special functions like climbing, storage etc., and are also useful for vegetative propagation.

Majority of the plants have green foliage leaves by which they prepare their own food materials and are said to be autotropic. Such green foliage leaves are absent in heterotropic plants namely the parasites and saprophytes. Parasites are plants which depend upon other living organisms for their food e.g., *Cuscuta.* Saprophytes are plants which derive their food materials from dead organic matter. eg. *Orabanche.*

Phyllotaxy

The mode of arrangement of the leaves on the stem is called *phyllotaxy* and it varies in different plants.

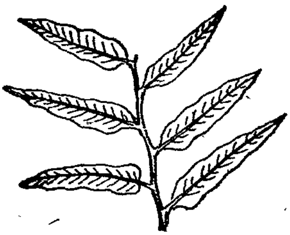

FIG. 3 50 Alternate

1. *Alternate:* There is only one leaf at each node. (*Fig.* 3.50)

2. *Opposite:* If there are two leaves arranged opposite to one another at each node, it is called opposite phyllotaxy. There are two variations in this type.

(a) *Superposed:* Such successive pairs of opposite leaves are all spread in one plane, then it is known as superposed. When viewed from above all the leaves are found to lie in two vertical rows. e.g., *Quisqualis indica, Psidium guajava* (*Fig.* 3.51).

FIG. 3.51
opposite and superposed

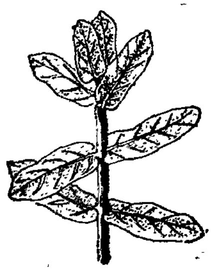

FIG. 3.52
Opposite and decussate

(b) *Decussate:* If the successive pairs of opposite leaves are arranged at right angles to one another, it is termed *decussate* e.g., *Calotropis gigantia, Ixora* (*Fig.* 3.52)

FIG. 3.53 Ternate

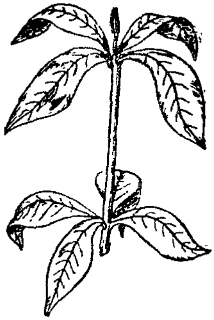

FIG. 3.54 Whorled

3. *Ternate:* When there are 3 leaves at each node, arranged in the form of a circle around the stem it is known as ternate. e.g., *Nerium odorum* (*Fig.* 3.53)

4. *Whorled:* When there are more than 3 leaves at each node arranged in a circle, it is termed whorled. In *Allamanda* there are 4 leaves at each noed. In *Alstonia* there are 5 to 7 leaves at each node. (*Fig.* 3.54)

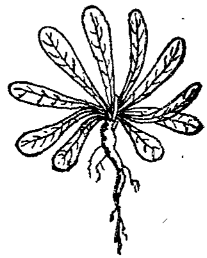

FIG. 3.55 Radical

5. *Radical:* Here the stem is condensed and short, found just above the soil level on which a cluster of leaves are arranged as in *Mollugo*. The leaves appear as though they start from the root directly. (*Fig.* 3.55)

Significance of Phyllotaxy

In order that the leaves may perform their normal functions efficiently, it is essential that all the leaves should be well exposed to sunlight and atmospheric air. The various kinds of phyllotaxies help in achieving this object and thus avoid over crowding and shading of the leaves by one another.

PARTS OF A LEAF

A normal foliage leafc onsists of the following parts: (*Fig.* 3.56)

I. Leaf base or *hypopodium*.
II Petiole or *mesopodium*.
III Leaf blade or lamina or *phyllopodium*.

I. Leaf base

The leaf base is the point of attachment of the leaf to the stem. In leguminous plants the leaf base is swollen and then it is known as *pulvinus*.

In most Monocotyledons, the leaf base becomes very prominent and winged. It is called a *sheathing leafbase* which clasps and covers the stem to a certain extent. (*Fig*. 3.57)

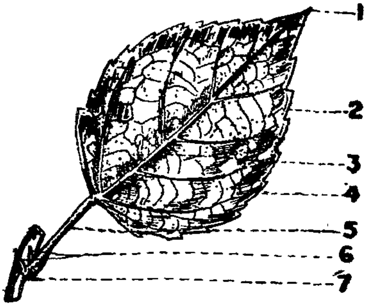

FIG 3.56 Parts of a leaf

1. Tip 2 Margin 3. Midrib 4. Lamina 5. Petiole 6 Stipule 7. Node

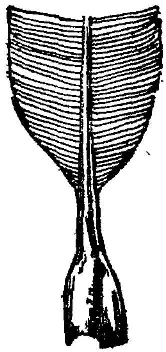

FIG. 3.57
Sheathing leaf base

The leafbase sometimes bears a pair of lateral outgrowths called *stipules*.

Stipules: Stipules are lateral outgrowths found at the point of attachment of leaf with the stem. Plants with stipules are described as *stipulate* and plants without stipules are called *exstipulate*. Stipules are commonly present among the dicotyledons, and they are rare among the Monocotyledons.

Stipules may be shed early and described as *caducous* as in *Michelia champaka*. If they remain for one season, they are called *deciduous* as in *Cassia tora*. If they remain as long as the foliage leaf, they are termed *persistent* as in Rose.

Kinds of stipules

According to their position, size, shape and colour, the stipules are of the following types.

1. *Free-lateral stipules:* There are two stipules, usually small and green in colour, borne on the two sides of the leaf base e.g., *Hibiscus rosa-sinensis.* (*Fig.* 3.58)

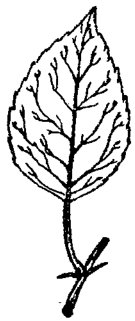

FIG. 3.58
Free lateral stipules

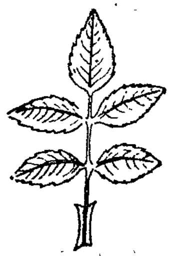

FIG. 3.59
Adnate stipules

2. *Adnate stipules:* Here the two lateral stipules are adherent to the petiole to a certain distance, so that the base of the petiole appears to be *winged.* e.g., Rose. (*Fig.* 3.59)

3. *Inter petiolar stipules:* In certain plants showing opposite phyllotaxy, stipules of the leaves fuse together at their margins so that they are placed in between the petioles. e.g., *Morinda. Ixora.* (*Fig.* 3.60)

FIG. 3.60
Inter petiolar stipules

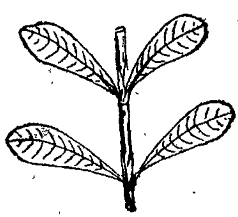

FIG. 3.61
Intra petiolar stipules

4. *Intra-petiolar stipules:* Two stipules of the same leaf fuse by their inner margins and appears to be present at the axil of a leaf. e.g., *Gardenia.* (Fig. 3.61)

FIG. 3.62 Ochreate stipules

5. *Ochreate stipules:* Stipules fuse together to form a hallow tube covering the internode to a certain height. e.g., ***Polygonum.*** (Fig. 3.62)

Modifications

6. *Foliaceous stipules:* Sometimes stipules are large green and leaflike as in *Cassia auriculata, Pisum sativum* and *Lathyrus.*

7. *Spinous stipules:* Stipules are modified into spines as in *Acacia arabica* and *Zizyphus jujuba.*

8. *Tendrillar stipules:* Stipules are modified into tendrils as in *Smilax.*

9. *Protective stipules:* In Banyan, *Magnolia,* there are scaly stipules which protect the vegetative buds.

II. The petiole

In most of the leaves petiole is present and it is described as *petiolate* as in Mango, the leaf without petiole is called *sessile* as in *Calotropis.*

Normally the petiole is solid and cylindrical. But sometimes it is modified:

1. In *Citrus,* the petiole is flat and is called *winged.* (Fig. 3.63).

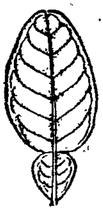

FIG. 3.63
Winged

FIG. 3.64
Tendrillar

FIG. 3.65
Inflated

2. In *Clematis* the petiole is *tendrillar* and useful for climbing. (Fig. 3.64).

3. In *Eichhornia*, the petiole is swollen and spongy enclosing much air and helps the plant to float in water. (Fig. 3.65)

4. *Phyllode:* If the petiole is flat and green similar to the leaf it is described as a *phyllode.* In *Acacia moniliformis* only phyllodes are present in the mature plant.

Phyllodes are also seen in *Parkinsonia aculeata* and *Oxalis bilimbi.* (Fig. 3.66)

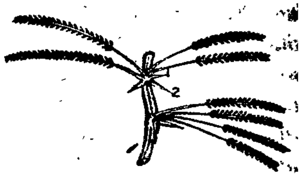

FIG. 3.66 Phyllode
1. Main Rachis
2. Stipules

Ordinarily, the leafblade lies in the same plane as the petiole, the lamina axis being a prolongation of the petiole. But in some cases, the petiole is attached to the centre of the lower surface of the lamina. The petiole is attached to the lamina at its right angles. This type of attachment of the lamina is called *peltate* e.g., Lotus, waterlily.

III. The lamina

The lamina is the most important part of the leaf as it performs the most important physiological functions like photosynthesis, respiration and transpiration.

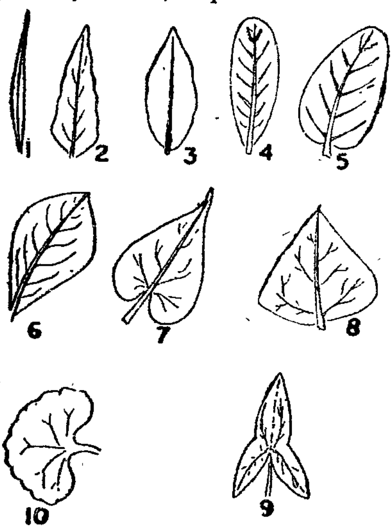

FIG. 3.67 Shapes of the leaf
1. Linear
2. Lanceolate
3. Oblong
4. Elliptic
5. Ovate
6. Obovate
7. Cordate
8. Deltoid
9. Sagittate
10 Reniform

The lamina is normally a flat structure. If it is differentiated into a definite upper and lower surface it is described as *dorsiventral* e.g., *Thespesia*. In many Monocotyledons and in the plants growing in shady situations, the leaf is placed in such a manner, that both the surfaces recieve equal light. There is no difference between the two surfaces. Such leaves are called *isobilateral leaves* e.g., *Eucalyptus*. The leaf of onion is cylindrical and is termed as *centric*.

The lamina differs widely in different plants and they are studied from the following aspects:

(a) Shape.
(b) Margin.
(c) Apex.
(d) Surface.
(e) Texture.
(f) Venation.
(g) Simple and Compound leaf.

(a) Shape of the lamina

The shape of the lamina varies with a variety of plants. (Fig. 3.67)

1. *Linear:* longer and slightly broader as in many grasses.

2. *Lanceolate:* when the leaf is long and tapering at the ends, with broadest part near the stalk and shaped like a lance as in *Nerium*, *Polyalthia*.

3. *Oblong:* when the blade is two or three times as long as it is broad, with parallel sides and the ends are rounded as in plantain and *Ixora*.

4. *Elliptic:* The lamina is broadest at the middle with tapering ends, and oval in shape as in Jack, *Vinca*.

5. *Ovate:* The lamina is slightly broader at the base than at the apex and is egg shaped as in Banyan.

6. *Obovate:* when the lamina is inversely egg shaped as in *Terminalia catappa*.

7. *Cordate:* when the lamina is heart shaped as in *Thespesia populnea*.

8. *Deltoid:* when the lamina is broadly wedge shaped and triangular as in leaflets of *Erythrina indica*.

9. *Sagittate:* when the lamina is similar to an arrow head, with two sharp straight lobes as in *Sagittaria* and *Arum*.

10. *Reniform:* when the lamina is bean shaped with a shallow depression at the base as in *Centella asiatica.*

(b) Margin of the leaf

The margin of the leaf may be:

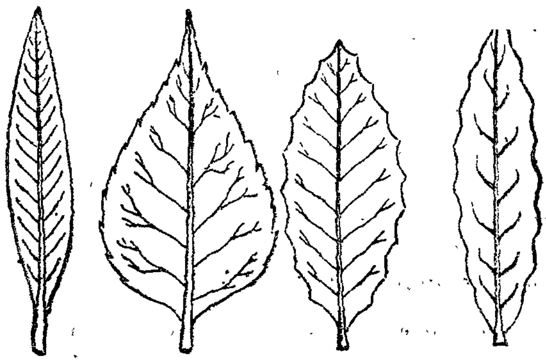

FIG. 3.68 Entire FIG. 3.69 Serrate FIG. 3.70 Dentate FIG. 3.71 Undulate

1. *Entire*—when the margin is smooth as in Mango (Fig. 3.68)

2. *Serrate*—when the margin is with teeth pointed towards the apex as in Acalypha (Fig. 3.69)

3. *Dentate*—margin toothed, the teeth are pointed outwards as in waterlily (Fig 3.70)

4. *Undulate*—margin is wavy as in *polyalthia.* (Fig. 3.71)

5. *Lobed*—when the margin is cut up into many lobes it is said to be *lobed* or *incised.*

(c) Apex of the leaf

The apex of the leaf differs widely in different plants (Fig. 3.72)

1. *Acute*—the tip is sharply pointed as in Mango

2. *Acuminate*—the tip is produced to a long fine point as in *Ficus religiosa*

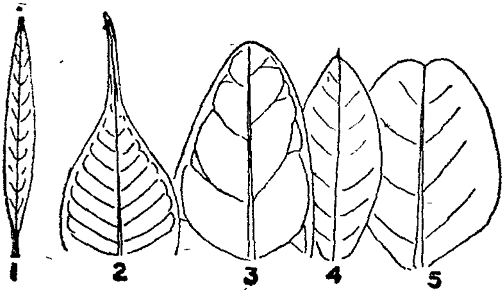

FIG. 3.72 Apex of the leaf
1. Acute 2. Acuminate 3. Obtuse 4. Mucronate 5. Retuse

3. *Obtuse*—the tip is blunt as in Banyan

4. *Mucronate*—the midrib is prolonged beyond the lamina as in *Cassia auriculata*

5. *Retuse*—there is a round shallow depression at the tip as in *Calophyllum*

(d) Surface of the leaf

The surface of the leaf may be:

1. *Glabrous*—when smooth and without any hairs as in Mango

2. *Hairy*—The leaf surface is covered with hairs.

(e) Texture

The texture of the leaf differs in different plants.

1. *Herbaceous*—when the leaf is thin and membranous as in Rose

2. *Coriaceous*—when it is firm and leathery as in Banyan

3. *Succulent*—when soft, thick and juicy as in *Bryophyllum*

(f) Venation

In most leaves, the petiole is continued into the lamina as *midrib* from which a number of lateral veins arise. The method of arrangement of veins in a leaf blade is known as ***venation.*** (Fig. 3.73)

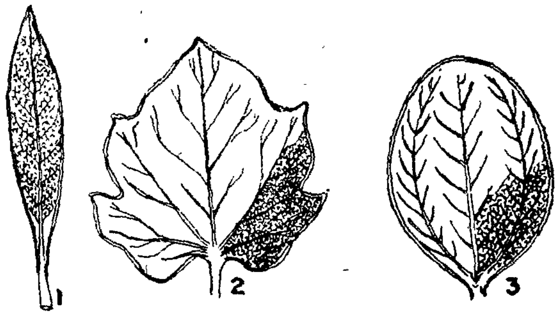

Fig. 3.73. Venation

1 Pinnately reticulate 2. Palmately reticulate (Divergent) 3. Palmately reticulate (Convergent)

Functions of the veins

1. They conduct water and mineral substances to all parts of the leaf.

2. They also conduct the prepared food material to other parts of the plant.

3. They form the skeleton of the blade and help in keeping the blade rigid so that it does not get crumpled up or torn easily.

4. They help in keeping the blade flat, so that they may be fully exposed to sunlight.

Venation follows certain basic patterns. The Angiosperm leaf shows two principal type of venation.

I. Reticulate venation

II. Parallel venation

I. Reticulate venation

There is a strong midrib from which numerous branches are given off in all directions so as to form a network covering the entire blade. This type is present in most of the Dicotyle-

donous plants like Mango, Castor etc. Reticulate venation is of two types:

1. *Pinnately reticulate or unicostate type:* In this type, there is a strong midrib or costa and it gives rise to a number of lateral veins towards the margin or apex of the leaf, like plumes in a feather. These are then connected by smaller veins which pass in all directions forming a network. e.g., *Ficus bengalensis*, *Psidium guajava*.

2. *Palmately reticulate or multicostate type:* Here instead of a single main vein (midrib), there are a number of equally prominent veins which arise from the tip of the petiole and radiate outwards or upwards along the blade as the fingers spread out from the palm of the hand.

(a) *Divergent*—when the main veins diverge towards the margin of the leaf as in Papaya, Cucurbits.

(b) *Convergent*—when the veins converge to the apex of the leaf as in *Zizyphus jujuba*.

II. Parallel venation

When the veins are all more or less of the same size and run parallel to one another the venation is said to be parallel. This type of venation is mostly seen in Monocotyledons. Parallel venation is of two kinds.

1. *Pinnately parallel:* In this type of venation the leaf has a prominent midrib which gives off several lateral veins which proceed parallel to each other towards the margin or apex of the leaf blade as in Banana, *Canna indica*.

2. *Palmately parallel:* A number of veins start from the tip of the petiole and spread in the leaf blade.

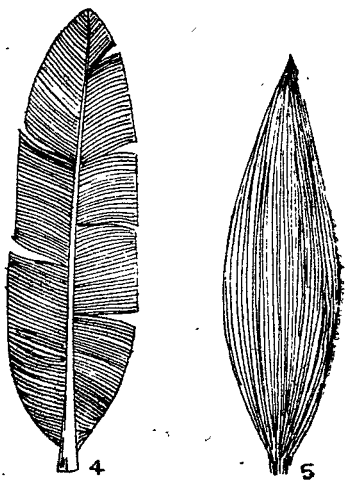

FIG. 3.73 (a)
4. Pinnately parallel 5. Convergnet

(a) *Divergent*—Starting from the petiole the veins radiate and spread out as in Palmyra.

(b) *Convergent*—when a number of veins run parallel to one another along the length of the blade and converge at the tip as in Bamboo and Grasses. [Fig. 3.73 (a)].

(g) Simple and Compound Leaves

A leaf is said to be *simple* when it consists of a single blade attached to the petiole. This blade may be entire or undivided as in Mango or lobed as in Cotton.

A leaf is said to be compound, when there is a main petiole bearing a number of blades, each having a small stalk of its own. The main petiole is known as a *rachis* and each blade a *leaflet* when the leaflets of a compound leaf are bigger, the leaf may look like a small branch bearing simple leaves. But the compound leaf may be distinguished from the branch by the following points:

1. The branch develops from an axillary bud of a leaf. There is an axillary bud in the axil of the main rachis of a compound leaf.

2. A branch will end in a terminal bud. A compound leaf has no terminal bud.

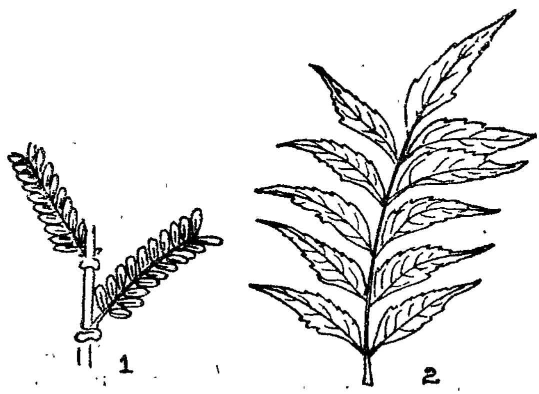

FIG. 3.74. Compound leaf
1. Paripinnate 2. Imparipinnate

3. The simple leaves of a branch will have axillary buds in their axils. The leaflets of a compound leaf do not have axillary buds.

4. A branch is always provided with nodes and internodes; while the rachis of a compound leaf is free from them.

Classification of compound leaves

The compound leaves may be broadly divided into

I. Pinnately compound leaves (Fig. 3.74)

II Palmately compound leaves (Fig. 3.75)

The classification of the compound leaves is given.

I. Pinnately compound leaf

Fig. 3.74 (a). Compound leaf Tripinnate

In this type, the leaflets are arranged laterally all along the length of the rachis like the plumes of a feather. This may be further subdivided into many types.

1. *Unipinnate:* when the rachis of the pinnately compund leaf bears the leaflets directly, it is said to be *unipinnate.* There are two types under this:

(a) *Paripinnate:* When the leaflets are evenly arranged on the rachis and if the rachis ends in a pair of leaflets, it is said to be paripinnate e.g., *Cassia auriculata.*

(b) *Imparipinnate:* This is similar to paripinnate type, but the tip of the rachis ends in a single leaflet. e.g., *Murraya exotica,* Rose.

In *Erythrina indica* there are three leaflets in a compound leaf. At first there are a pair of lateral leaflets on the rachis. Then there is elongation of the rachis which bears a single leaflet at its tip. This is referred to as *trifoliate imparipinnate.*

2. *Bipinnate:* The compound leaf is twice pinnate i.e., the main rachis produces secondary rachii which bear the leaflets. e.g., *Acacia arabica.*

3. *Tripinnate:* The leaf is thrice pinnate i.e., the primary gives rise to many secondary rachii which in turn give rise to tertiary rachii and bear the leaflets. [Fig. 37.4 (a)]. e.g., *Moringa*.

4. *Decompound:* when the leaf is more than thrice pinnate, it is said to be decompound as in *Coriandrum sativum.*

II. Palmately compound leaf

The tip of the petiole bears terminally a number of leaflets radiating from a common point like fingers arising from the palm. This may be further subdivided into a number of other types according to the number of leaflets.

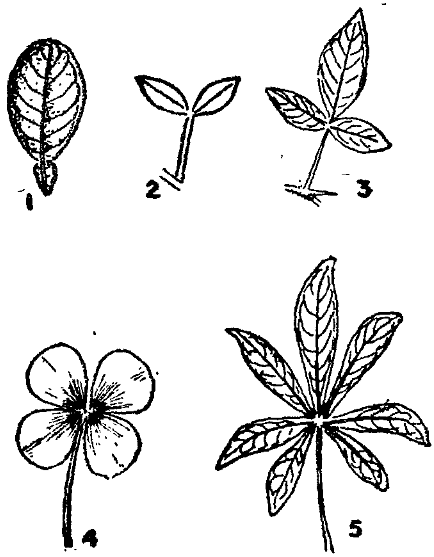

Fig. 3.75 Palmately Compound leaf
1 Unifoliate 2. Bifoliate 3. Trifoliate 4. Tetra foliate 5. Multifoliate

1. *Unipinnate:* When there is only one laflet as in *Citrus*. This will appear like a simple leaf. But it is actually a compound leaf because there is a joint at the junction of the blade and the winged petiole.

2. *Bifoliate:* When there are two leaflets from the tip of the petiole as in *Bignonia grandiflora, Hardwickia binata.*

3. *Trifoliate:* When there are three leaflets attached to the tip of the petiole as in *Aegle marmelos.*

4. *Tetrafoliate:* When there are four leaflets at the tip of the petiole as in *Oxalis tetraphylla.*

5. *Multifoliate:* There are many leaflets arising from the tip of the petiole like the digits of a palm as in *Bombax malabaricum.*

Modifications of lamina

In addition to the normal functions like photosynthesis, respiration and transpiration the leaf blade or lamina does certain other functions also. In order to perform such specialised functions, the lamina becomes modified or metamorphosed into distinct forms. These are as follows:

1. *Storage leaves:* Leaves of *Xerophytes* and *Halophytes* become fleshy because of the storage of water, mucilage and food. Such leaves contain a storage tissue. e.g., *Agave americana, Suaeda maritima.*

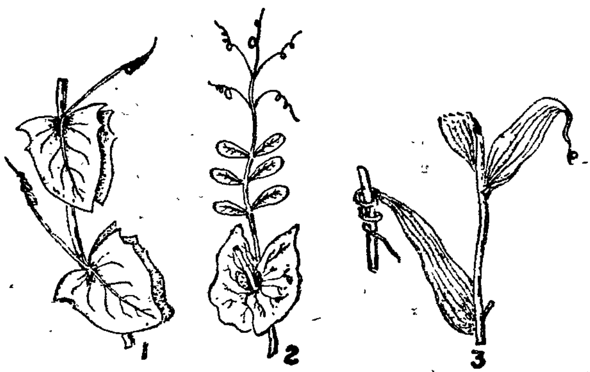

FIG. 3.76 Leaf tendrils
1. Lathyrus 2. Pisum sativum 3. Gloriosa superba

2. *Leaf tendrils:* The leaf blade or its portions are modified into tendrils and help the plants in climbing (Figure 3.76)

(*a*) In *Lathyrus*, the entire leaf is modified into tendril.

(b) In *Pisum sativum*, the terminal leaflets of the compound leaf are modified into tendril.

(c) In *Gloriosa*, the leaf tip is modified into tendril.

3. *Hooks:* In *Bignonia unguiscati*, the three terminal leaflets are modified into hooks which help in climbing (Figure 3.77)

FIG. 3.77 Hooks

FIG. 3.78 Leaf Spines

4. *Leaf spines:* In Barberry, the main leaves are modified into spines whereas the axillary buds develop into leaves. (Figure 3.78)

5. *Specialised leaves as in insectivorous plants:* Thre is a group of interesting plants known as *insectivorous plants*. They live in habitats where there is deficiency of nitrogenous substances. In order to conpensate this, these plants capture the small insects and derive nitrogenous substances from them.

Drosera: This is a small herbaceous plant with a rosette of spoon shaped leaves. The leaf blade consists of peculiar tentacles wtith swollen heads secreting a sticky glittering fluid. The fluid shines like dew in the sun and hence the plant is popularly known as 'Sun dew'. Small insects mistake this for honey and reach the leaf surface. The marginal tentacles bend downwards and capture the insect. The glandular hairs surrounding the prey secrete the digestive juices and the insect is digested and absorbed. After the digestion is over, the

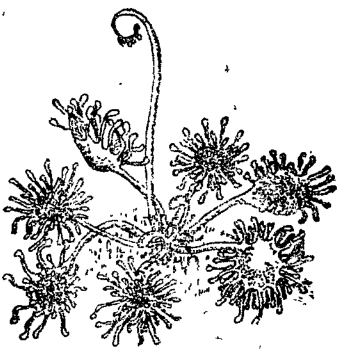

FIG. 3.79 Drosera

tentacles expand and are ready for another catch. (Figure 3.79) In Nepenthes and Utricularia leaves are variously modified for this purpose. (Fig. 3.80; 3.81)

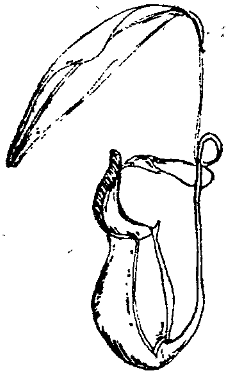

Fig. 3.80 Nepenthes

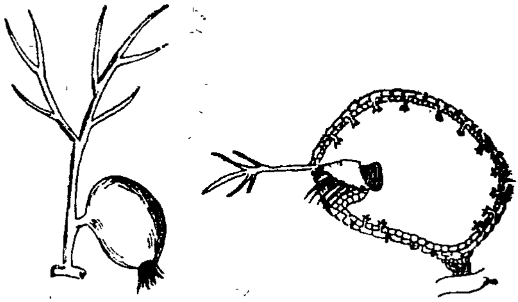

Fig 3.81 Utricularia

Heterophylly

Normally a plant bears leaves which are similar to each other, characteristic of the species. They are said to be *isophyllous*. When different types of leaves are produced on one and the same plant it is known as *heterophylly*. There are many types of heterophylly.

1. *Environmental heterophylly*: This is seen in partially sub-

Fig 3.82
Environmental heterophylly

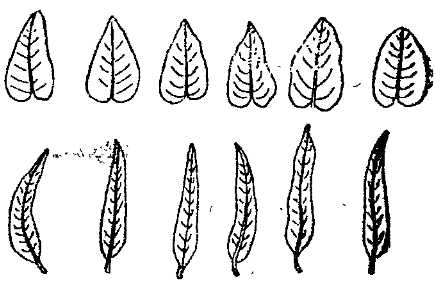

Fig. 3.83
Developmental heterophylly

merged aquatic plants like *Limnophilla heterophylla* and *Ranunculus aquatilis.* (Fig 3.82)

These plants grow in shallow waters where they are rooted in the soil. The submerged leaves are often very much dissected and are reduced to mere filaments. The aerial leaves are simple with broad lamina.

2. *Developmental heterophylly:* This is associated with the change from juvenile to mature foliage in the development of the individual. e.g., Eucalyptus. (Figure 3.83)

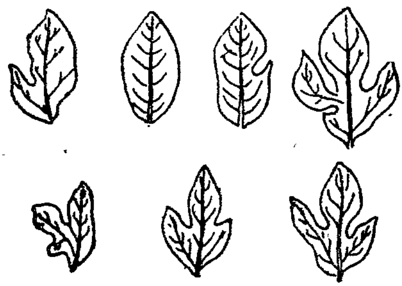

FIG. 3.84 Habitual heterophylly

3. *Habitual heterophylly:* Habitual heterophylly involves the formation on the main shoots of foliage leaves of different sizes and to a lesser extent of different shapes, apparently without any functional significance. e.g., *Artocarpus integrifolia* (Fig. 3.84)

Leaf folding

Due to the limitations of the space, the young leaves enclosed in the bud are tightly packed and often show remarkable foldings. This is not usually a mere crumpling of the young lamina, but is evidently the result of co-ordinated growth.

The manner in which each individual leaf is folded or rolled is known as *ptyxis* and this is remarkably constant in each species. Leaves may be folded in different ways (Fig. 3.85)

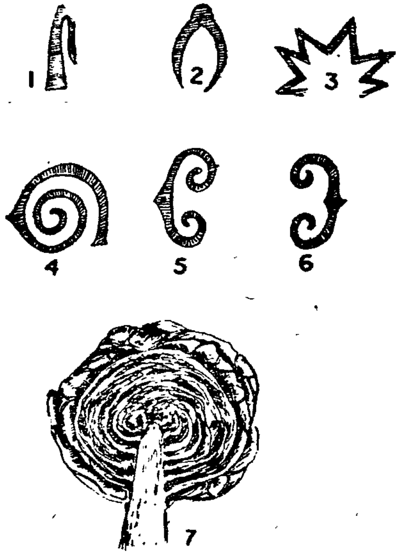

FIG. 3.85 Ptyxis

1. Reclinate
2. Conduplicate
3. Plicate
4. Convolute
5. Involute
6. Revolute
7. Crumpled

1. *Reclinate:* when the upperhalf of the leaf is bent upon the lower half as in *Eriobotrya joponica.*

2. *Conduplicate:* when the leaf is folded lengthwise along its midrib as in *Bauhinia.*

3. *Plicate:* leaf is folded longitudinally several times along some prominent veins as in Palmyra.

In the following cases leaves are rolled in different ways:

4. *Convolute:* when the leaf is rolled from one margin to the other as in Banana.

5. *Involute:* when the two margins are rolled on the upper surface of the leaf towards the midrib or the centre of the leaf as in Lotus and waterlily.

6. *Revolute:* when the leaf is similarly rolled down towards its lower surface as in *Nerium odorum.*

7. *Crumpled:* when the leaf is irregularly folded as in Cabbage.

Vernation

The mode of arrangement of all the leaves in the bud is called *Vernation.* The arrangement of foliage leaves in the vegetative bud and that of the floral leaves in the floral bud

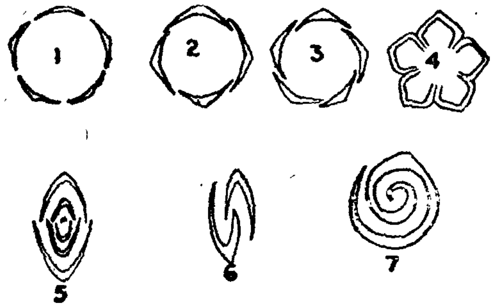

Fig. 3.86 Vernation

1. Valvate 2. Imbricate 3. Twisted. 4. Induplicate
5. Equitant 6. Half equitant 7. Supervolute

are nearly the same and the same type of terminologies are used to explain the identical types in both cases. (Fig. 3.86)

A. The individual leaves are flat or slightly convex.

1. *Valvate:* when the leaves are arranged in almost a circle, while their margins just touch one another without overlapping.

2. *Imbricate:* when the margins of the leaves overlap one another without any order.

3. *Twisted:* such overlapping of the leaves is regular in one direction so that one margin of every leaf overlaps the leaf on one side, while the other margin is being overlapped by its adjacent leaf, thus giving a twisted appearance in the bud.

4. *Induplicate:* It is a variety of valvate where the edges of the leaves, instead of touching one another are bent inwards for a little distance.

B. The individual leaves are folded or rolled in the following ways:

5. *Equitant:* conduplicate leaves standing face to face and one completely overlapping the other by both the margins.

6. *Half-equitant* when such overlapping is incomplete so that only one half of a blade is inside the other.

7. *Supervolute:* when a convolute leaf encloses another presenting a completely rolled up bud.

THE LEAF

(ANATOMY)

Leaf is an expanded flattened lateral organ or an appendage present at determined loci of the stems and branches known as the nodes. They are arranged in a particular manner with respect to a species. Leaves are of different kinds and are broadly classified into vegetative and floral leaves. The vegetative leaves represent cotyledons, scale leaves (cataphylls), various floral bracts (hypsophylls), prophylls (the first formed scale leaves of a lateral branch) and foliage leaves. Among these different kinds of leaf, the foliage leaves are the main photosynthetic organs of a plant although the remainder also takes part in photosynthesis to varying extent. The first formed leaves of any plant emerging out of germination of the seeds are known as the cotyledons but they are only transitory organs. The scale leaves are usually protective and if fleshy storage in function as in *Allium cepa* (Onion). Bracts are also usually protective in function but in certain cases by assuming colours other than green offer attraction to the organs enveloped by them. (e.g., *Euphorbia pulcherrima* Willd.—Poinsettias). The foliage leaves are anatomically more differentiated and specialized than other kinds of leaf. They are characterized by the expanded flattened part known as the lamina, limb or blade which may be simple or compound (divided into certain number of smaller units called leaflets) and having a petiole (stalk) or not. Furthermore there are veins arranged in a particular manner (pinnate, palmate, parallel) and number characteristic of a species and they are

particularly laterally inserted with respect to a central more prominent and stouter vein known as the midrib. As shown below the veins and midribs which are recognized in morphological sense represent in the anatomical sense, the vascular system containing xylem and phloem within.

Just as the stems and roots consist of epidermis, ground tissue and vascular tissues when analyzed in the broad sense, the leaves also are characterized similarly by these three tissue systems. On either side of the leaf, epidermis is present consisting of a single layer of cells known respectively as abaxial (lower) and adaxial (upper) epidermis (Fig. 3.91) What is known as the ground tissue in the axial organs is present in the leaf as mesophyll tissue which in turn is differentiated into palisade and spongy tissues. The vascular tissues occur in the form of veins which are usually marked by profuse branchings and anastomosis depending upon their degree of development and the examples. The general anatomical characteristics of various foliar tissues and their respective functions may be briefly considered before the consideration of the internal structure of the leaf of *Ricinus communis* is attempted.

Epidermis: Trichomes (hairs) of different kinds are usually present. Sometimes the epidermal cells may also contain crystals. For other details, see under tissues.

Mesophyll: The mesophyll as mentioned earlier is considered to be equivalent to or homologous with the ground tissues of other organs. The mesophyll is usually differentiated into palisade and spongy mesophyll (Fig. 3.91). The palisade cells are slightly or conspicuously elongated radially thereby appearing cylindrical or rod like as seen in the transections of the leaf (Fig. 3.91). They are aligned at right angles to the adaxial epidermis in the case of dorsiventral leaves and to both adaxial and abaxial epidermis in the isobilateral or unifacial leaves (leaves having similar structure on both sides). However, they present the appearance of a compact arrangement and seemingly devoid of intercellular spaces in transection (Fig. 3.91). But in reality the intercellular spaces are abundantly present as could be seen clearly in the longitudinal sections of the

leaves (Fig. 3.94). Leaves possessing the palisade tissue in the upper side and the spongy tissue in the lower side are known as the bifacial or dorsiventral leaves. If on the contrary the palisade tissues occur on both sides of the leaves thereby appearing similar in structure on both sides such leaves are called unifacial or isobilateral leaves as in *Nerium odorum* Soland (Indian oleander). The number of palisade layers is variable ranging from 1-4 and the intercellular space system is much larger in it than in the spongy mesophyll. On the other hand, the spongy mesophyll cells are irregular in size and shape (Fig. 3.91). They are usually loosely arranged coupled with conspicuous intercellular spaces and occupy more or less the lower half of the leaves namely the abaxial half (Fig. 3.91). Both palisade and spongy mesophyll cells are living and rich in chloroplasts (Fig. 3.91) and thus they are qualified to function as the important and effective photosynthetic tissues. The mesophyll cells that are immediately adjoining and enveloping the vascular bundles are both structurally and functionally specialized and different from the remainder. They constitute the bundle sheath or border parenchyma (Figs. 3.90, 3.91). This is also interpreted as equivalent to endodermis on the basis of its positional relationships with vascular bundles although the typical casparian strips are mostly indistinguishable in them (Figs. 3.90, 3.91).

Vascular tissues: The vascular tissues are manifested externally and recognizable in the form of several veins. But in the anatomical sense as mentioned earlier, they represent vascular tissues which often show ramifications of first, second, third order and so on and anastomosis among them (Fig. 3.93). The veins, because of the frequent ramifications and anastoses, subdivide the mesophyll ground tissue into a series of smaller polygons and thus resulting finally in the smallest subdivisions known as the areoles (Fig. 3.93). The ultimate veinlets or vein endings usually extend into and terminate in the areole (Fig. 3.93). The quantum of vascular tissues developed within a vein depends upon its order of development and its size. In other words, the larger veins such as the midrib contain greater amount of vascular tissues (Fig. 3.92) and the smallest veins the lesser amount (Fig. 3.90). Thus a progressive reduc-

tion in the amount of vascular tissues may be witnessed from the largest to the smallest veins. This kind of quantitative variation in the vascular tissues of the veins is accompanied by qualitative variation also. The vascular tissues as seen in the form of bundles in the transections of the leaves show xylem facing the adaxial (ventral) and phloem the abaxial(dorsal) sides (Figs. 3.87, 3.91, 3.92). This alignment is inevitable because the vascular tissues as they are departing and deviating from the stem, undergo deflection in such a way that the xylem which is the innermost in the stem becomes the uppermost in the blade and the phloem which is the outermost in the former occupies the lowermost position in the latter. As far as the midrib is concerned, interesting variations of simple and complex nature pertaining to the number, size, shape, types and pattern of arrangements of vascular bundles may be observed. For example, the vascular bundles may be united forming a cylinder or in the form of discrete units arranged in the form of a ring or in the form of an arc (abaxial) confronted by an adaxial vascular bundle (*Ricinus communis*; Fig. 3.87) or not or the vascular bundles may be arranged in more than one ring or scattered, or they may have normal orientation or show torsion and inversion etc. The smallest vein or the veinlet is reduced to such an extent that the xylem part of it usually contains tracheid (Fig. 3.90) and likewise the phloem part is represented by parenchyma instead of sieve elements etc. But in the case of larger veins both vessels and sieve elements are represented in full complement in the xylem and phloem parts of the vascular bundles.

Description of Transection of Lamina—*Ricinus communis* L. (Castor bean)—Figs. 3.87; 3.91; 3.92)

The thickness of the lamina described is about 0.9 mm. Lamina is dorsiventral or bifacial. *Cuticle* is rather thin on either surface but thicker over the midrib. *Epidermis*: adaxial and abaxial epidermal cells are broad, and variable in size and shape (Fig 3.91). *Mesophyll* is differentiated into distinct palisade and spongy tissues, the former is about 2 layered. The palisade tissue consists of elongated cells and are arranged perpendicular to the adaxial epidermis (in transverse section).

They appear to be devoid of apparent intercellular spaces in transection (Fig. 3.91). The spongy tissue consists of more or less compactly arranged tangentially elongated, tabular cells and showing little variation in size and shape (Fig. 3.91). The cells of both palisade and spongy tissues possess abundant chloroplasts (Fig. 3.91) and thus becoming essentially photosynthetic. *Stomata* (Figs. 3.88; 3.89) occur in both adaxial and abaxial epidermis and hence called amphistomtic. The guard cells are 2 in number, rounded in outline and each one of them is characterized by a small horn like projection in its upper side known as outer ledge (Fig. 3.88). The guard cells are unevenly thickened and surrounded by a pair of subsidiary cells (Figs. 3.88; 3.89). The substomatal chamber is narrow and small (Fig. 3.88). Midrib is prominent. This is adaxially ribbed and abaxially keeled and appear broadly 'U' shaped (Fig. 3.87). The abaxial and adaxial hypodermis in the midrib consists of 6-10 layers of angular collenchyma (Fig. 3.92). The midrib ground tissue is constituted of colourless parenchyma cells and arranged with intercellular spaces They contain abundant druses (Fig. 3.87).

Vascular system. This is represented by an abaxial arc of continuous vascular tissues and confronted adaxially by a solitary bundles (Figs. 3.87; 3.92). Primary xylem elements of the arc shaped strand are arranged in radial rows with protoxylem pointing towards adaxial epidermis while those of the adaxial bundle towards the centre (Figs. 3.87; 3.92). Primary phloem forms a continuous tissue on the abaxial side of the arc shaped strand and on the adaxial side of the solitary vascular bundle (Figs. 3.87; 3.92). The vascular bundles of the laminal parts are rather small, rounded in outline and surrounded by colourless parenchyma cells forming bundle sheath (Fig. 3.91). The veinlet contains a single, solitary angular tracheid surrounded by chlorophyllous cells (Fig. 3.90). *Idioblasts:* druses are very abundant throughout the lamina particularly in the phloem parenchyma and the ground tissue of the midrib (Fig. 3.87) and in this respect some of the palisade cells are enlarged to such an extent that they appear cyst like enclosing very large druses.

LEAVES

(PHYSIOLOGY)

The normal functions of leaves are (1) Photosynthesis (i.e., manufacture of food) and (2) Transpiration (i.e., evaporation of water). Besides these normal functions, leaves also do some other functions like storage and propagation.

I. Photosynthesis

The primary activity of green leaves is photosynthesis. Photosynthesis is the synthesis of carbohydrates from carbondioxide and water by the chloroplasts making use of the energy of sunlight. It is also known as carbon assimilation since it results in the formation of compounds containing carbon. This process of photosynthesis is essentially the conversion of light energy into chemical energy, of carbon compounds to be available for the life processes of plants, animals and man.

Raw materials or source of material

The raw materials which react in photosynthesis are carbondioxide and water. Water is absorbed from the soil by the roots and reaches the leaves through the xylem of stem. Carbondioxide is obtained from the air that diffuses into leaves through the stomata. Carbondioxide cannot enter the cells as gas. It dissolves in water present in the cell walls and this solution diffuses into the palisade and spongy cells of the leaf.

Chlorophyll

The chloroplast is the site of photosynthesis. It contains a green pigment called chlorophyll. Chlorophyll is not a single compound but it is a mixture of four different pigments namely Chlorophyll a, Chlorophyll b, Carotene and Xanthophyll. Chlorophyll does not contain iron but iron is necessary for the formation of chlorophyll.

Chlorophyll spectrum

Chlorophyll absorbs certain wavelengths of light. When a beam of light is passed through a glass prism, the light gets

separated into different bands of colours, red at one end and violet at the other end and the remaining colours, indigo, blue

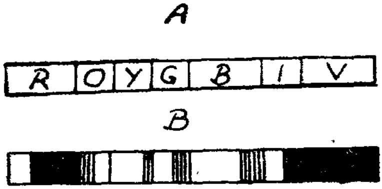

FIG. 3..

A. Solar Spectrum B. Chlorophyll absorption spectrum

green, yellow and orange, in between these two. This is called a solar spectrum. (Fig. 3.95)

If an extract of chlorophyll is placed in a glass container between the path of light and the prism, the normal solar spectrum is not formed. But dark bands appear in the regions of certain colours like red, blue and violét and less dark bands in the region of other colours. This shows that certain wavelengths of light are partially or completely absorbed by the chlorophyll solution. Thus the chlorophyll absorbs more of certain colours of the wavelengths of light like red, blue, indigo and violet. These colours are used in the light reaction of photosynthesis. The dark bands are called absorption bands and the spectrum obtained by using chlorophyll extract is known as absorption spectrum of chlorophyll.

Factors affecting photosynthesis or conditions necessary for photosynthesis

The factors affecting photosynthesis may be classified into external and internal factors.

External factors

1. *Light:* Light is the most important factor for photosynthesis. It supplies energy necessary for photosynthesis. Photosynthesis will not take place in darkness. An increase in the intensity of light increases the rate of photosynthesis. But an excessively high intensity of light decreases the rate of photosynthesis.

2. *Carbondioxide.* Carbondioxide is the source of the carbon for the organic substances formed in the plant. Plants obtain CO_2 from the atmosphere which contains only about 0·03% of the gas by volume. Higher concentration of CO_2 (above 1%) decreases the rate of photosynthesis.

3. *Water:* Water is necessary for photosynthesis as it is one of the raw materials in the process of photosynthesis. Palisade cells can carry on their function of food manufacture only when they are in a turgid condition for which water is essential. The amount of water actually used is very small. Yet its deficiency may decrease the rate of photosynthesis and also tend to close the stomata, thereby preventing the entry of CO_2 into the leaves.

4. *Temperature* The optimum temperature, i.e., the favourable temperature, for photosynthesis in most plants is 35°C. A further increase or decrease in temperature affects the rate of photosynthesis.

Internal factors

1. *Chlorophyll:* Chlorophyll is essential for photosynthesis. Chloroplasts function as photosynthetic organs only when they contain chlorophyll. Chlorophyll absorbs light energy and supplies the energy for the preparation of carbohydrates. Non-green plants do not have the photosynthesising capacity.

2. *Protoplasmic factor:* There is some unknown factor within the protoplasm of the cell which affects the rate of photosynthesis. This unknown factor is probably enzymatic in nature and is called protoplasmic factor.

3. *Accumulation of end products of photosynthesis:* Usually food materials are translocated as soon as they are formed. Sometimes during photosynthesis, more food material is formed than what is translocated. This accumulation of end products may decrease the photosynthetic rate to some extent.

Chemistry of photosynthesis

The overall reaction of photosynthesis may be written as,

$$6\,CO_2 + 12H_2O \xrightarrow[\text{light}]{\text{Chlorophyll}} C_6H_{12}O_6 + 6H_2O + 6O_2 \uparrow$$

According to recent findings, photosynthesis occurs in two stages; (1) Light reaction and (2) Dark reaction.

(1) Light reaction

This reaction takes place only in the presence of light and hence it is called light reaction. It is also known as Hill's reaction or photochemical reaction. During this reaction, water is split up into hydrogen and oxygen by using light energy. This process is known as photolysis of water.

When light falls on chlorophyll, the chlorophyll molecule absorbs light energy and becomes excited or activated. This activated chlorophyll molecule releases an electron which is at high energy level. The electron moves from one hydrogen acceptor to another and during its movement, it releases energy A part of this energy is utilised for the formation of a high energy compound Adenosine Triphosphate (ATP).

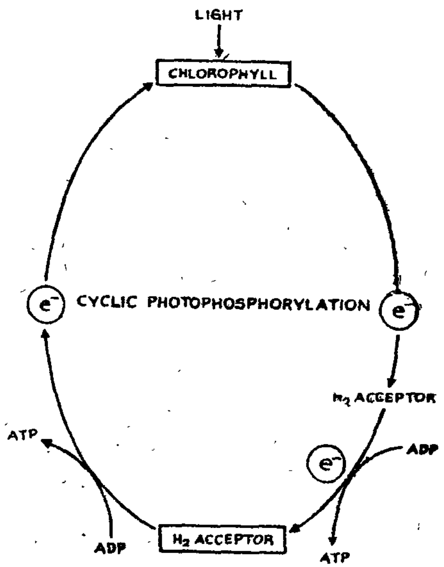

FIG 3.95 (a). Cyclic photophosphorylation

The process of formation of ATP in the chloroplast is known as photophosphorylation. The electron which is released from

the activated chlorophyll once again returns to the chlorophyll after transferring its energy to ATP. Again the cycle is repeated. This type of electron transport is known as cyclic electron transport or cyclic photophosphorylation, since it involves the formation of ATP also. [Fig. 3.95 (a)].

Some electrons are used for the splitting up of water i.e., photolysis of water. Water is split up into hydrogen (H^+) ions and hydroxyl (OH^-) ions. Since hydrogen ion cannot remain in a free state, it is immediately taken up by a hydrogen acceptor called NADP (Nicotinamide Adenine dinucleotide phosphate). The NADP is now reduced to $NADPH_2$. Two hydroxyl ions combine to produce water and oxygen. The

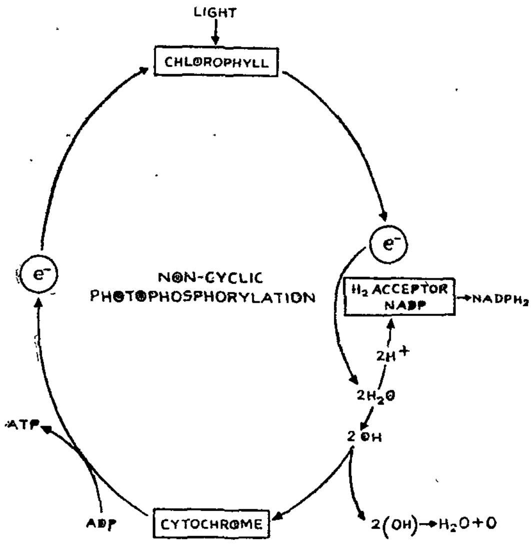

FIG. 3.95 (b) Non-cyclic photophosphorylation

Oxygen is released as gas. In this process, the hydroxyl ion also releases an electron. This electron is taken by a pigment called cytochrome. The cytochrome then donates this electron to chlorophyll. During the electron transfer ATP is formed. The electron released from the chlorophyll does not return to the chlorophyll and the electron that returns to the chlorophyll is derived from another source i.e., from hydroxyl ion of water This type of electron transport is known as

non-cyclic electron transport or non-cyclic photophosphorylation. [Fig. 3.95 (b)].

(2) Dark reaction

This reaction does not require light and therefore it is called dark reaction. It is also known as Blackman's reaction or purely chemical reaction. This process involves the reduction of CO_2 to a carbohydrate and it is known as fixation of CO_2.

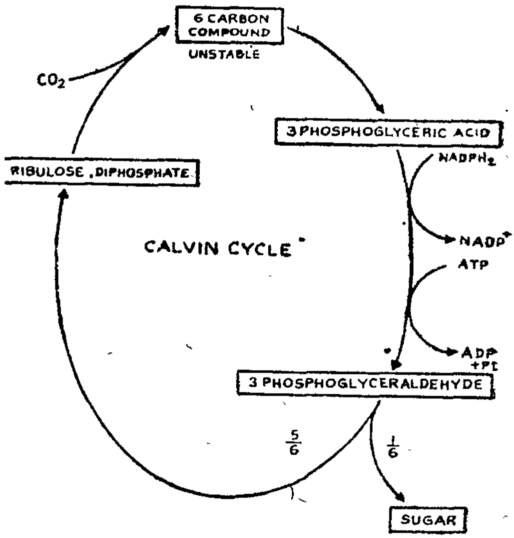

FIG. 3.95(c) Calvin cycle

First CO_2 combines with a 5 carbon compound namely Ribulose diphosphate present in the leaves to form a 6 carbon compound. This 6 carbon compound is not stable and therefore it immediately forms 2 molecules of a 3 carbon compound called phosphoglyceric acid. The phosphoglyceric acid is then converted into phosphoglyceraldehyde. The $NADPH_2$ and ATP formed during light reaction take part in the conversion of phosphoglyceric acid to phosphoglyceraldehyde. After this reaction, $NADPH_2$ and ATP become NADP and ADP respectively.

Of 6 molecules of phosphoglyceraldehyde, one molecule forms the end product of photosynthesis. A part of it is utilised for the immediate use of body building and respiration by the cell and the remaining part of it is converted into sugars and stored away. The other five molecules of phosphoglyceraldehyde after undergoing a series of changes form Ribulose diphosphate. This cycle of changes is called ' Calvin Cycle '. Energy required for this process is supplied by ATP formed in the light reaction. [Fig. 3.95 (c)].

Experiments

1 *To show that oxygen is evolved during Photosynthesis:* A few bits of a water plant namely Hydrilla are placed in a beaker filled with water. They are covered by a short stemmed funnel. Care is taken to see that the stem of the funnel is

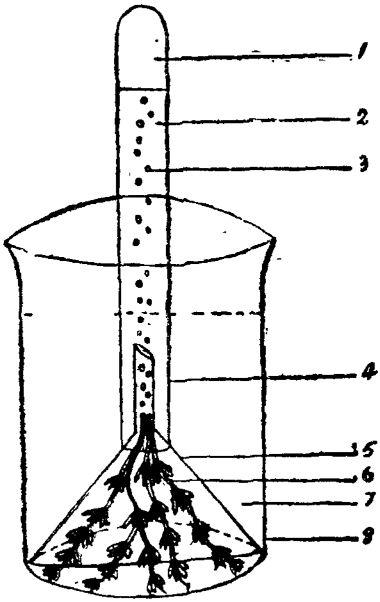

Fig. 3.95 (d)

Experiment to show the evolution of oxygen during photosynthesis

1. Oxygen
2. Water
3. Air bubble
4. Test tube
5. Funnel
6. Water plant
7. Water
8. Beaker.

below the level of water and also that the cut ends of the bits are inside the stem of the funnel. A test tube filled with water is inverted over the stem of the funnel. The set up is kept in the sunlight.

After sometime, bubbles of gas will be seen to be coming up from the cut ends of the plant. The gas collects in the test tube by the displacement of water. When sufficient quantity of gas has been collected in the test tube, the test tube is removed and a red hot splinter is introduced. The splinter burns into a flame, thereby proving that the gas collected is oxygen. This experiment proves that oxygen is evolved during photosynthesis. [Fig. 3.95 (d)].

2. *Experiment to show that starch is formed during photosynthesis:* A leaf is removed from a plant which is exposed to sunlight. It is dipped in boiling water for sometime to kill the tissues. Then the leaf is put in warm alcohol. The chlorophyll which is soluble in alcohol, is removed from the leaf and the leaf becomes white. The decolourised leaf is treated with iodine. The leaf turns blue, thus showing the presence of starch.

3. *Experiment to show that light is necessary for photosynthesis—Ganong's light screen experiment:* A potted plant is kept in darkness for about 2 days to make the leaves starch free. One of the leaves of the plant is removed and tested for starch. This leaf will not turn blue, showing the absence of starch. To another leaf of the plant, a light screen is attached. A light screen consists of a metal box and a disc attached to it by a clip. A star shaped figure is cut in the disc. The plant is then placed in sunlight.

After few hours, the leaf is removed and tested for starch. It is found that only the portion of the leaf which was exposed to the light turns blue while the portion of the leaf covered by the light screen and not exposed to light remains colourless. This experiment proves that light is necessary for photosynthesis (Fig. 3.96).

4. *Experiment to show that CO_2 is essential for photosynthesis—Mohl's experiment:* A pot plant is kept in darkness for 24 hours to make the leaves starch free. A small quantity of caustic potash solution is taken in a wide mouthed bottle which is provided with a split cork. A leaf of the plant is introduced into the bottle through the split cork in such a way that the

terminal half of the leaf is inside the bottle and the basal half, outside. The bottle is kept in position with a support. The apparatus is kept in sunlight.

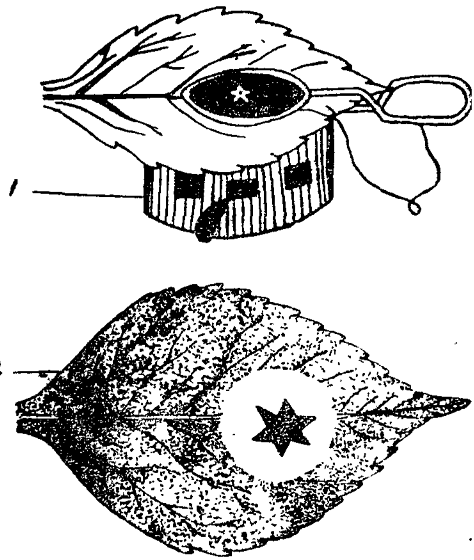

Fig. 3.96 Ganong's light screen experiment
1. light screen 2 leaf after starch test.

After sometime the leaf is removed and tested for starch. The portion of the leaf which was outside the bottle turns blue. This is because CO_2 is available for this portion from the atmosphere. The portion of the leaf which was inside the bottle does not turn blue. This is because caustic potash solution inside the bottle absorbs all the carbondioxide. This experiment proves that CO_2 is essential for photosynthesis. (3.97)

5. *Experiment to show that chlorophyll is necessary for photosynthesis:* Croton leaf shows coloured patches including green. Such a leaf is described as a variegated leaf. A croton plant is placed in darkness for a day or two. Then the plant is exposed to sunlight. The green portions are marked on the leaf. The leaf is then removed and tested for starch. It is seen that only the green portions of the leaf turn blue, thereby indicating the

presence of starch. This experiment proves that chlorophyll is necessary for photosynthesis.

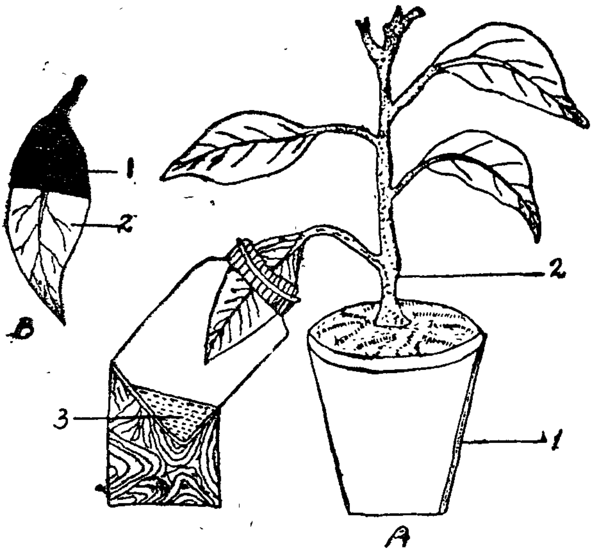

FIG. 3.97 Mohl's experiment

A. 1. pot 2. Plant 3. Caustic potash solution

B. Leaf after starch test

1. portion of the leaf with the starch
2. portion of the leaf without starch

II. Transpiration

Plants absorb a large amount of water from the soil through the root hairs. All the water absorbed by the plant is not utilised by it. Only a very small quantity of water is retained in the plant for its life processes. The greater part of water is lost by the aerial parts of the plant in the form of water vapour. The loss of water in the form of water vapour from the aerial parts of the plant is known as transpiration.

Transpiration may take place from any part of a plant which is exposed to the atmosphere. However, the leaves are the principal organs of transpiration.

Transpiration is of three types; stomatal, cuticular and lenticular. Most of the transpiration from leaves takes place through the stomata and this is called stomatal transpiration. Some transpiration takes place from the epidermal cells of the leaf through the cuticle and this is known as cuticular transpiration. Loss of water vapour takes place also through the small openings called lenticels present in the fruits and woody stems and this is termed lenticular transpiration.

Transpiration can be demonstrated by simple experiments.

1. *Experiment to show that transpiration takes place through leaves—Bell Jar experiment:* Two well watered pot plants are taken. The mouths of the pots are covered with rubber sheets to prevent the evaporation of water from the soil. In one of the plants all the leaves are removed and vaseline is smeared over the cut surfaces. The two plants are then kept separately under bell jars. The set up is left in sunlight. After some

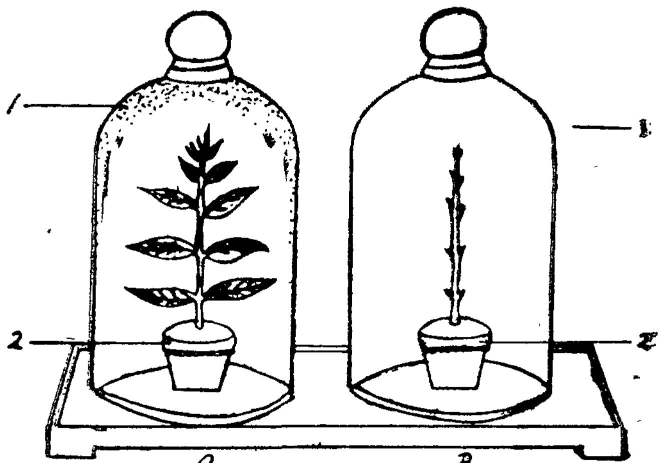

FIG. 3.98 Bell jar experiment

A. Plant with leaves B. Plants where leaves are removed

1. Water drops

2. Rubber sheet

time it is observed that water drops appear on the inner surface of the bell jar enclosing the plant with leaves. In the

second case where leaves have been removed, there is no such accumulation of water. In the first case the formation of water droplets is due to loss of water from the aerial parts of the plant. The absence of water vapour in the second case shows that transpiration takes place through the leaves. (Fig. 3.98)

2. *Experiment to measure the rate of transpiration using Ganong's Potometer:* The rate of transpiration may be measured by the use of an apparatus called Ganong's potometer.

Ganong's potometer consists of a horizontal graduated capillary tube with one end bent downwards and the other end bent upwards. The end which is bent upwards is dilated and fitted with a one holed rubber cork. A water reservoir with a stopcock is attached to the horizontal tube. The whole apparatus is mounted on a stand.

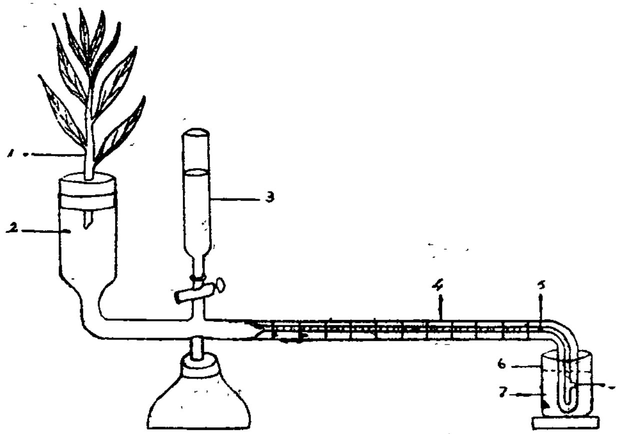

FIG. 3.99 Ganong's potometer
1. Cut branch 2. Water 3. Water reservoir 4. Graduated capillary tube 5. Air-bubble 6. Beaker 7. water 8. pore

The apparatus is filled with water. A small branch is cut under water and fixed to the one holed cork. The connections are made air tight. An air bubble is introduced at the end which is bent down and this end is kept immersed in a beaker of water.

As the leaves transpire, the cut end of the branch absorbs water and the air bubble moves along the graduated horizontal

tube. From the distance travelled by the air bubble in a particular time, the rate of transpiration can be calculated.

The experiment can be performed by keeping the apparatus in direct sunlight, in shade and so on, in different environments and the rate of transpiration under different environmental conditions can be observed. (Fig 3 99)

Transpiration causes a suction force in the xylem, by means of which ascent of sap takes place. This can be proved by the following experiment.

3, *Experiment to demonstrate suction due to transpiration—Lifting power of transpiration:* The apparatus consists of a wide tube open at both ends and fitted at each end with a one holed rubber cork. To one end is attached a long narrow tube. The apparatus is filled with water and a fresh shoot is cut and inserted under water through the cork in the other end. The apparatus is made perfectly air tight. The lower end of the long narrow tube is dipped in mercury in a beaker. This apparatus is fixed to a stand.

After a few hours it is seen that mercury has risen up in the tube to a considerable height. This shows that the branch loses water through leaves by transpiration. Transpiration causes a suction force and this causes the mercury to rise up in the tube, and this gives a measure of the lifting power of transpiration. (Fig. 3.100)

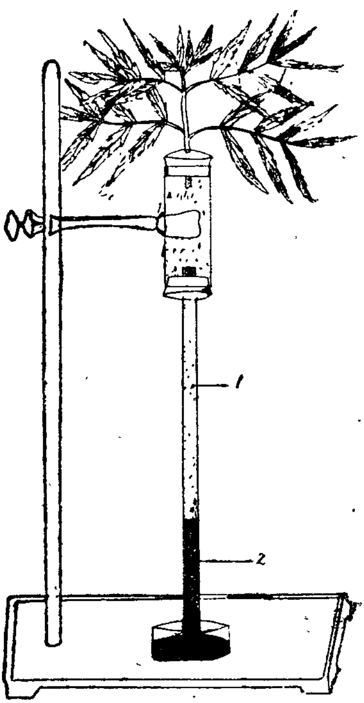

FIG 3.100

Experiment to demonstrate the suction power of transpiration
1. Water 2. Mercury

Mechanism of stomatal opening and closing

The stomata are considered as the chief organs of transpiration. Stomatal movements are brought about by charges in the volume and shape of the guard cells. The expansion and contraction of the guard cells must be due to the turgidity and flaccidity respectively. When the guard cells absorb water from the surrounding cells, they become turgid and they curve away from each other, resulting in the widening of the stomatal pore. When the guard cells lose water, they become flaccid and the stoma is closed by the straightening of the curvature of the guard cells.

Factors influencing transpiration

Transpiration is influenced by a number of factors which can be classified into external and internal factors.

External factors

1. *Light:* Transpiration in light is much greater than in darkness. Light increases transpiration by raising the temperature of the leaves. Secondly, it causes the stomata to open widely, leading to greater transpiration. Thus light affects transpiration in two ways.

2. *Temperature* Increase of temperature increases transpiration.

3. *Wind:* High wind increases transpiration because it instantly removes water vapour from the transpiring surfaces.

4. *Humidity:* A humid atmosphere decreases transpiration. When the atmosphere is very dry, loss of water vapour from the leaves is very great. When the atmosphere becomes moist, loss of water vapour is less.

Atmospheric pressure and available soilwater also affect the rate of transpiration.

Internal factors

1. The rate of (stomatal) transpiration depends upon the number, size and distribution of stomata on the leaves.

2. The presence of thick cuticle, wax etc. reduces the rate of (cuticular) transpiration.
3. The internal structure of the leaf and water content of the mesophyll cells also affect the rate of transpiration.

Adaptations to reduce excessive transpiration

Plants growing in dry places show special adaptations for preventing excessive transpiration. Some of the adaptations are:

1. The stomata are reduced in number. They are placed in a sunken cavity and covered with protective hairs e.g., Nerium leaf.
2. Leaves are very small (e.g., Euphorbia) or reduced to scales (e.g., Casuarina) or modified into spines (e.g., Opuntia).
3. Surfaces of leaves possess thick cuticle or a coating of wax or numerous hairs.
4. The epidermis of the leaf is many layered e.g., Nerium.
5. Leaves place themselves vertically to avoid strong sunlight.
6. In grasses, the leaves roll up so that the surface on which stomata chiefly occur is less exposed to air.

Significance or uses of transpiration

Some consider transpiration as of great benefit to the plant while others regard it as harmful.

Advantages

1. Transpiration helps the plant to get rid of the excess of water absorbed by the roots.
2. Transpiration helps in regulating the temperature of the plant.
3. Transpiration helps in raising water to the top of the tree by acting as a sucking force and also helps in distributing water throughout the plant.

Disadvantages

The stomata are the organs through which not only transpiration but also exchange of gases for the vital activities of the plant like photosynthesis and respiration takes place. Hence the stomata cannot be kept closed for a long time. When they are kept open for photosynthesis and respiration, transpiration will also take place. Therefore transpiration is regarded as a necessary evil or unavoidable evil. Moreover, if the rate of transpiration is high and the supply of soil water is not sufficient, the plant may face a great shortage of water in its cells.

The loss of water from plants may also take place in the form of liquid and this process is known as guttation or exudation. It is commonly found in the early morning in plants like Grasses, *Colocasia* etc., as water drops along the margins or apices of leaves. These water drops contain some solutes. Guttation takes place through pores called water stomata or hydathodes present in the leaves.

III. Storage

In some leaves, water and food materials are stored up. Such leaves are usually fleshy and succulent. e.g., *Agave*, *Aloe*, *Bryophyllum*. In some plants, the leaves are modified into pitcher like structures for storing water and humus, e.g., *Nepenthes*, *Dischidia*. Scale leaves of bulbs also store water and food materials.

IV. Propagation

New plants arise from the leaves of some plants and this method is called vegetative propagation.

In *Bryophyllum*, the leaves are thick and succulent and have small notches in their margins. Small buds are produced in the notches of the margins.

In *Begonia*, a few adventitious buds are produced on the surface of the leaf, when these buds or the leaves fall, they develop roots and grow into new plants.

ECONOMIC IMPORTANCE OF LEAVES

Leaves are very useful to us in many ways.

1. *Food:* The leaves of *Amaranthus*, *Alternanthera*, *Sesbania grandiflora* are used by us as greens.

2. *Spices:* The leaves of *Murraya koenigii*, *Coriandrum sativum* are used to give flavour to other dishes.

3. The green leaves of *Musa sapientum*, *Canna indica* are used as dining plates.

4. The leaves of *Piper betel* are useful for chewing.

5. Tea is prepared from the leaves of *Thea senensis* which is used as a beverage.

6. *Fibres* are extracted from the leaves of *Agave americana* and are used in various ways.

7. Tannins are extracted from the leaves of *Rhus glabra*, *Rhus typhina* and *Cinnamomum typhina.* Tannins are used in tanneries.

8. *Medicines:* Many leaves are used in allopathic and indigenous medicines.

(*a*) Allopathic medicines are prepared from the leaves of following plants:

Atropa belladonna—medicine for cough.
Erythroxylon coca—medicine for Hysteria.
Digitalis purpurea—medicine for Blood pressure.
Eucalyptus spp—medicine for head ache.

(*b*) The leaves of the following plants are extensively used in the preparation of Ayurvedic and Siddha system of medicines. e.g. *Abutilon indicum*, *Eclipta alba*, *Phyllanthus niruri*, *Solanum trilobatum* etc.,

9. *Dye:* Indigo dye is extracted from the leaves of *Indigofera tinctoria.*

10. *Green Manure:* The leaves of following plants are useful as green manure. (e.g.) *Tephrosia purpurea*, *Gliricidia maculata*, *Indigofera tinctoria*, *Crotolaria juncea.*

11. *Cattle feed:* The leaves of the following plants are useful as cattle feed. (e.g.) *Cyanodon dactylifera*, *Panicum maximum*, *Pennisetum purpureum*, *Medicago sativa*, *Cenchrus ciliaris*

CHAPTER 4

INFLORESCENCE

When a plant gives rise to branches and leaves, it is said to be in its *vegetative phase*. After this, the plant gives rise to flowers, fruits and seeds, which is called *reproductive phase*. Reproduction by seeds derived from flowers is known as *sexual reproduction* and it involves a highly complicated process, in contrast to *vegetative propagation*. Each flower is a specialised piece of shoot, adopted for the purposes of reproduction. The flowers may occur singly or in clusters. Flowers borne singly are called *solitary*. The solitary flower may either be *axillary* replacing an axillary shoot, or *terminal*, replacing the terminal bud. When the flowers are arranged in clusters, they are grouped together in branches which are quite different from vegetative branches. *The specialised branch system with a number of flowers is known as Inflorescence.*

The main axis of an inflorescence is called the *peduncle*. The individual flowers are attached to this peduncle by small stalks known as *pedicels*. The flowers without stalks are termed *sessile*.

In some plants with underground stems, the peduncle directly arises from the underground stems. Such a peduncle is known as a *scape*. The scape may give rise to a solitary flower as in Lotus, or an inflorescence as in *Scilla* and *Allium cepa*.

Classification

Inflorescences can be classified on two basis

I. On the position of the inflorescence in the shoot system.
II. On the sequence of flowering within the inflorescence.

Classification of Inflorescence

I. *On the basis of position:* On the basis of position of the inflorescence in the shoot system, inflorescence is classified into *terminal axillary* and *intercalary*. Terminal inflorescence is found at the tips of terminal and axillary branches. Intercalary.

Inflorescence

1 Racemose	2 Cymose	3 *Mixed types*	4 *Special types*
A. Rachis elongated (a) *flowers stalked*	1. Solitary cyme	1. Thyrsus	1. Hypanthodium (cyconium)
1. Raceme 1a. panicle (b) *flowers sessile*	(a) Terminal cyme (b) Axillary cyme	2. Verticillaster	2. Cyathium
2. Spike 2a. Compound spike 2b. spikelet	2 Simple Dichasium 2a Compound Dichasium		
3. Spadix 3a. Compound spadix	3. Monochasial cyme 3a. Helicoid 3b. Scorpiod.		
B. Rachis shortened			
4. Corymb 4a. Compound corymb	4. Polychasial cyme		
C. Rachis suppressed			
5. Umbel 5a. Compound umbel			
D Rachis flattened to form receptacle			
6. Head 6a. Compound Head			

inflorescence is seen in *Callistamon lanceolatum.* Here the terminal inflorescence is dormant for sometime. In the meanwhile, the growth of the shoot system is continued so that the dormant inflorescence is left behind. After this, the inflorescence comes out of the stem and appears to be intercalary If the inflorescence is found on older branches, it is known as *cauliflory* as in Jack, *Polyalthia.*

2. *On sequence of development:* On the basis of the flower development within the inflorescence, it can be broadly divided into two types

(I) Racemose or indeterminate

(II) Cymose or determinate

If the characters of the inflorescence is of both types, it is called a *mixed type.* If the inflorescence could not be assigned to any of these types mentioned, it is included under *special type.*

I. Racemose type of Inflorescence

Main axis of the inflorescence grows indefinitely bearing the flowers directly or on its branches.

The main axis is *indefinite* or *indeterminate* in its growth bearing a number of lateral flowers in the axils of small leaflike structures called *bracts*. The oldest flowers are at the bottom of the inflorescence and the youngest towards the apex. This type of arrangement of flowers is called *acropetal succession*.

When the flowers are brought to the same level by the lengthening of the lower pedicels, the order of opening of the flowers is from the periphery to the centre i.e., *centripetal*. Racemose inflorescences may be further sub-divided according to the nature of the growth of the peduncle and presence or absence of pedicel.

A. With the main axis elongated

(a) *Flowers stalked*

1. *Raceme:* In a raceme, the inflorescence axis is very much elongated and a number of stalked flowers arise in the axils of bracts in an acropetal succession. The pedicels of flowers are of the same length.

e.g., *Crotaria verrucosa, Cleome viscosa* (Fig. 4.1)

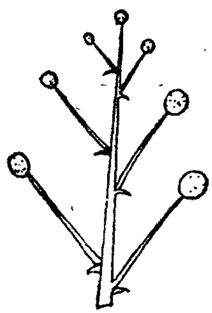

FIG. 4.1 Raceme

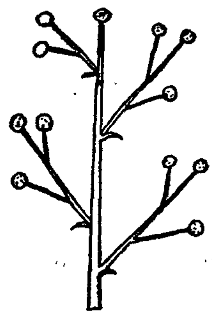

FIG. 4.2 Compound raceme

1a. *Panicle or Compound raceme:* When the main axis of a raceme branches and the flowers are borne not directly on the axis but on its brances, then the inflorescence is called a panicle. e.g., *Ceasalpinia pulcherrima, Peltophorum ferrugineum.* (Fig. 4.2)

(b) *Flowers sessile:*

2. *Spike:* This is just like the raceme; but the flowers are sessile e.g., *Achyranthes aspera, Piper longum* (Fig. 4.3)

2b. *spikelet:* Instead of a number of flowers as in a spike, there are only a few flowers in a spikelet as in the flowers of *Cyperaceae* and *Gramineae* e.g., Paddy, *Cyperus.* (Fig 4.4)

The bract of a spikelet is called a *Glume* or *Lemma* and the bracteole is known as a *Palea.*

3. *Spadix:* This is a variation of spike in which the rachis is thick and fleshy and the flowers are sessile and are protected by a large bract called *Spathe* e.g., *Colocasia antiquorum.* (Fig. 4.5)

FIG. 4.3 spike FIG. 4.4 Spikelet FIG. 4.5 spadix

In the fleshy axis of the spadix male flowers are arranged at its top, neutral flowers in the middle and female flowers at the bottom. e.g., *Caladium.*

3a. *Compound spadix:* When the axis of a spadix branches and flowers are arranged on the branches, e.g., *Cocos nucifera.*

Usually the whole inflorescence is covered by a thick boat shaped spathe, but in some palms, separate segments of spadix are covered with smaller spathes known as *Spathellae.*

B. Peduncle shortened

4. *Corymb:* Here the peduncle is not very much elongated as in a raceme. Flowers found on the lower part of the axis are having longer pedicels and flowers found towards the top of the

axis will have shorter pedicels so that all the flowers are placed at the same level. e.g., *Cassia auriculata*, *Gynandropsis pentaphylla*. (Fig. 4.6)

C. Rachis suppressed

5. *Umbel:* Here the inflorescence axis is very much shortened than in Corymb types. There are a cluster of bracts on the tip of the shortened axis. These bracts are called *involucre of bracts*. At the axils of these bracts, flowers having stalks of equal length arise, so that all the flowers are brought to the same level. e.g., *Hydrocotyle asiatica* (Fig. 4.7)

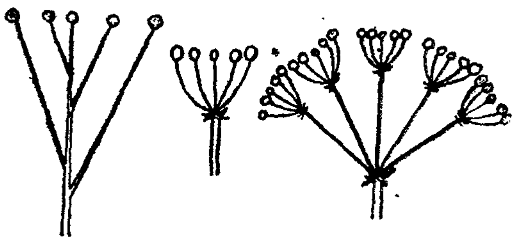

FIG. 4.6 Corymb FIG. 4.7 Umbel FIG. 4.8 Compound umbel

Corymb and umbel inflorescences may be compared for clarification. In corymb, the pedicels vary in length and are attached to the peduncle at various levels. In an umbel, the pedicels are of the same length attached at the tip of the shortened axis.

5a. *Compound Umbel:* When the axis of an umbel branches, it is known as a compund umbel. These branches from the umbel are called *rays*. At the tips of these rays there are a group of small bracts called *involucre of bractlets*. A single umbel in a compund umbel is called an *umbellet*. e.g., *Daucas carota*, *Coriandrum sativum*. (Fig. 4.8)

D. Rachis flattened to form receptacle

6. *Head or Capitulum:* Here the axis forms a flattened, more or less convex receptacle, on which the small flowers called *florets* are arranged in a centripetal order. Head inflorescence consists of three parts

(*a*) Involucre of bracts

(*b*) Receptacle

(*c*) Florets

(a) *Involucre of bracts:* Inflorescence is surrounded by a cluster of green bracts. They are leathery, scaly or spiny differing in colour in different plants. These bracts do the duty of the calyx of individual florets. They protect the young flowers and fruits.

(b) *Receptacle:* The floral axis is short and condensed and becomes fleshy and horizontally elongated. It may be sometimes cone shaped or globular. The surface of the inflorescence may be smooth or hairy.

(c) *Florets:* On the fleshy receptacle there are several small flowers arranged in an acropetal succession and the opening of the flowers is centripetal. Individual flowers are sessile and arises from the axil of a dry bracteole called *palea*, e.g., *Heliumthus annuus.*

If all the florets of the head are similar in sex, structure and function, the inflorescence is called a *Homogamous head.*

If the florets of the head differ in structure function and sex, the infloresence is called a *Heterogamous head.*

The florets of the inflorescence may be of two kinds namely the *ray florets* and *disc florets.*

6a. *Compound Head:* Here the main axis is branched and several head inflorescences are found on the branches, e.g., *Lagasca mollis*, *Echinops echinatus.*

II. Cymose type of inflorescence

Here the growth of the main axis of the inflorescence is *limited* or *determinate.* It stops its growth after giving rise to a flower with a bracteole. The bracteole of this flower becomes the bract of the second set of flowers which arise in its axil.

In the cymose type of inflorescence, the central flowers of the inflorescence are the oldest and the basal flowers are younger which is in contrast to the racemose types. Further, in cymose

inflorescence the opening of the flowers is from the centre to the periphery that is *centrifugal* whereas it is centripetal in racemose types. There are many types under cymose inflorescence.

1. *Solitary cyme:* Even if there is a single flower in plants, it is described as a solitary cyme. If it is terminal in position it is called a *terminal solitary cyme* as in *papaver somniferum.* If the solitary flower is axillary in position it is referred to as *axillary solitary cyme* as in *Thespesia populnea.* (Fig. 4.9)

FIG 4.9 Solitary cyme
1. Axillary 2. Terminal

2. *Simple dichasium:* The main axis ends in a flower. This flower has two bracteoles and from the axil of each, a lateral flower develops. In this cluster of three flowers the central flower is the oldest and opens first, while the two lateral flowers are younger and open later. This type is just opposite to the conditions found in racemose clusters. e.g., Jasmine (Fig. 4.10)

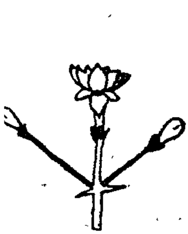

FIG 4.10 Simple Dichasium

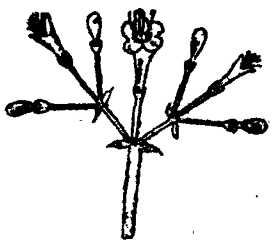

FIG. 4.11 Compound Dichasium

2a. *Compound dichasium:* The main axis ends in a flower and from the bracteoles of this flower, two lateral flowers rise. These

two lateral flowers have two bracteoles each, which become the bracts of the third set of flowers. This results in the formation of regular clusters in a symmetrical manner. This type is also known as a *Dichasial cyme* since this cluster consists of two simple cymes in addition to the central older flower. e.g., *Ixora, Clerodendron*, (Fig. 4.11)

3. *Monochasial cyme:* In this type, the main axis ends in a flower and it produces only one lateral branch at a time, ending in a flower. The lateral and succeeding branches again produce only one branch at a time like the primary branch.

There are two types under monochasial cyme (Fig. 4.12)

1 2

FIG 4.12 Monochasial cyme
1 Helicoid cyme 2 Scorpioid cyme

3a. *Helicoid cyme:* The main axis ends in flower and stops its growth. From this, several lateral branches develop successively on the same side forming a sort of helix as in *Hemelia patens, Begonia.*

3b. *Scorpioid cyme or Cincinnus:* The main axis ends in a flower and stops its growth. From this lateral branches develop alternately to the right and the left. e.g., *Heliotropium curassavicum,*

4. *Polychasial cyme:* The main axis ends in a flower and at the same time produces a number of lateral flowers simultaneously around the main axis. e.g., *Calotropis, Asclepias.*

Mixed types

These inflorescences are partly racemose and partly cymose.

1. *Thyrsus.* In the main axis, several simple dichasial cyme clusters of flowers are arranged in a racemosed manner. Each dichasial cluster consists of a terminal large flower and two lateral young flowers e.g., *Ocimum sanctum*, (Fig. 4.13)

2. *Verticillaster:* The inflorescence start as two dichasial cymes in the axils of the two opposite leaves. The branches of the dichasial cymes develop into monochasial scorpiod cymes in such a way that they enclose the main axis. The flowers are sessile. e.g., *Leucas aspera, Leonitis* (Fig. 4.14)

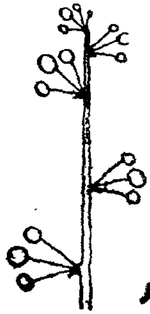

Fig. 4 13 Thyrsus

Fig. 4.14 Verticillaster

Special types

The infloresences could not be assigned either to racemose or cymose types and are treated as special types.

1. *Syconium:* The receptacle is fleshy forming a hollow cavity, more or less pearshaped and with a narrow opening at the top called *Ostiole.* The ostiole is guarded by scales. The flowers are all unisexual, arranged on the inner wall of the cavity. Here the female flowers develop at the base of the cavity and the male or neutral flowers higher up towards the top.
e.g., *Ficus bengalensis, Ficus carica.* (Fig. 4.15)

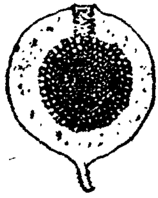

Fig. 4.15 Hypunthodium

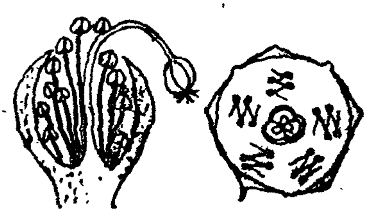

Fig. 4.16 Cyathium

2. *Cyathium:* This is a special kind of cymose inflorescence found in the genus *Euphorbia,* reduced to look like a single flower.

There is a cupshaped structure formed by the union of the bracts with beautifully coloured nectaries found on its top. The extremely reduced flowers are arranged on a convex receptacle. There is a central female flower reduced to a pistil, subtended by a long stalk. This is surrounded by five groups of reduced male flowers arranged in the form of monochasial scorpiod cymes. Each male flower is having a short stalk, a filament and two antherlobes, arising from the base of a scaly bract. e.g., *Euphorbia heterophylla*, *Poinsettia pulcherrima* (Fig. 4.16)

CHAPTER 5

THE FLOWER

The flowers are the most conspicuous structures in plants and are characteristic feature of phanerogams. They are connected with the reproductive phase of the plant which is a very manifest property of life.

The flower is a reproductive dwarf shoot consisting of an axis, bearing the essential organs like Androecium and Gynoecium with some accessary organs like calyx and corolla.

Parts of a flower

The flower develops from the flower bud. The flower consists of nodes and internodes similar to the vegetative shoot. But here the internodal portions are very much condensed. As in the shoot system the flower has got a floral axis. The tip of the floral axis is known as thalamus, torus or receptacle. The floral leaves are inserted on the floral axis similar to the leaves on the vegetative shoot. The prefoliation of the young leaves is like the aestivation of floral leaves.

Generally a flower consists of four whorls of floral parts

1. *Calyx* composed of *sepals.*
2. *Corolla* consists of *petals.*

These two whorls are not directly taking part in reproduction. Hence they were called *non-essential organs.* But it is better to call them as *accessory organs.*

3. *Androecium* (Micro sporophylls): is made up of stamens which represent the male reproductive part of the flower.

4. *Gynoecium:* is made up of *carpels* (*Megasporophylls*) and in the female reproductive part of the flower. Since Androecium and Gynocium are directly taking part in reproduction. they are called essential organs.

The following is a list of technical terms useful in the general description of the flower.

I Pedicel

1. *Pedicellate:* A flower with a pedicel.

2. *Sessile:* A flower without a pedicel.

II Bract and bracteole

1. *Bracteate:* A flower that arises in the axil of a bract or subtended by a bract.

2. *Ebracteate:* A flower without a bract.

3. *Bracteolate:* A flower with bracteoles.

4. *Ebracteolate:* A flower without bracteoles.

III Complete and incomplete flowers

1. *Complete flower* is one in which all the four whorls of floral parts are present.

2. *Incomplete flower* is one in which any one or more of the floral parts are absent.

   (a) *Achlamydous:* The calyx and corolla are absent in the flower.

   (b) *Apetalous:* The corolla alone is absent in the flower.

IV Sex distribution

1. *Bisexual, Hermaphrodite, Perfect or Monoclinous:* Flowers in which both androecium and gynoecium are present.

2. *Unisexual, Imperfect or Diclinous:* Flowers in which only one set of essential organs namely either the gynoecium or the androecium is present and not both.

   (a) *Male or staminate flower:* only androecium is present.

   (b) *Female of pistillate flower:* only gynoecium is present

   (c) *Monoecious:* Flowers unisexual and both male and female flowers are present in the same plant e.g., *Cocos nucifera*

   (d) *Dioecious:* Flowers unisexual and the male and the female are present in two different plants. e.g., *Caryca papaya, Borassus flabellifer.*

   (e) *Polygamous:* Bisexual and unisexual flowers are present in the same plant.

V Symmetry of the flower

(*A*) *In arrangement*

1. *Acyclic:* The floral parts are spirally arranged on an elongated thalamus e.g., *Magnolia.*

2. *Cyclic:* Floral members of different whorls are arranged alternate to each other. For example corolla is alternately arranged to calyx. e.g., *Calotropis.*

3. *Hemicyclic:* Amongst the four whorls of floral leaves, calyx and corolla are arranged in a cyclic manner and androecium and gynoecium arranged in an acyclic manner e.g., *Annona squamosa.*

(*B*) *In numbers*

1. *Anisomery:* With unequal number of floral parts in each whorl of flower.

2. *Isomery:* With equal number of floral parts in each of the whorls. This may further be divided into two types.

(*a*) *trimerous flower:* Floral parts in each whorl are in threes or multiples of it. e.g., Monocotyledonous flowers.

(*b*) *tetramerous or pentamerous flower:* Floral parts in fours or fives or in the multiples e.g., Dicotyledonous flowers.

(*C*) *Floral symmetry in form:* In some flowers the individual floral parts of a whorl may be similar in structure and form whereas in some other flowers they may be difference in structure and form. Accordingly the flowers may be divided into two major groups.

1. Symmetrical flowers.

2. Asymmetrical flowers.

1. *Symmetrical flowers;* The flower with a symmetry is called is called a symmetrical or a *regular flower.* This may be divided into two types. (Fig 5.1).

(a) *Actinomorphic or radial symmetry:* Here the floral members are proportionately arranged on the thalamus and the indivual floral parts of a whorl are similar in structure and form so that the flower may be divided into two equal halves through any vertical plane passing through the axis. e.g., *Thespesia populnea.*

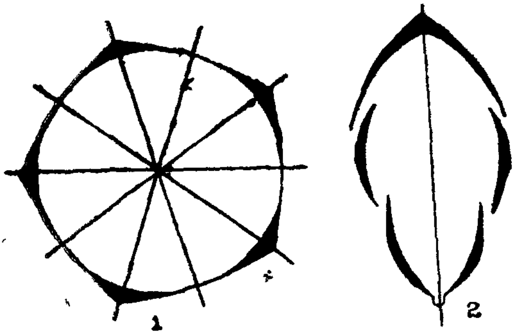

Fig. 5.1 Symmetry
1. Radial Symmetry 2. Bilateral Symmetry

(b) *Zygomorphic or bilateral symmetry;* There are some flowers the individual parts of the whorl differ in form and structure so that it can be divided into two equal halves only if it is cut in one vertical plane of the axis.
e.g., *Crotalaria verrucosa.*

2. *Assymetrical or irregular flowers:* If the individual floral parts of the whorls are quite different in structure and form where the flower cannot be divided into two equal halves if it is cut along any vertical plane of the axis. e.g., *Canna indica.*

Bracts and Bracteoles: Bracts are special leaves (hypsophylls) at whose axils, the flowers are borne. They serve for the protection of flower buds in the young stage. There are also small structures in between flower and bract known as bracteoles.

Variations of bracts and bracteoles

1. *Leafy or foliaceous* bracts are seen in *Adhatoda vasica* and *Acalypha indica.*

2. *Petaloid bracts* are seen in *Bougainvillaea spectablis* which are brightly coloured and attract the insects (Fig. 5.2)

FIG. 5.2 Petaloid bracts

FIG. 5.3 Involucre of bracts

3. *Spathy bracts:* These are large thick boat shaped bracts called *spathes* covering the whole or part of the inflorescence as in *caladium.*

4. *Involucre of bracts:* In the head inflorescence, a group of green sepaloid bracts occur around the base of the inflorescence e.g., *Helianthus annus* (Fig. 5.3)

5. *Scaly bract:* In head inflorescence in addition to the involucre of bracts, scaly bract is also present, in the axil of which individual flower arises.

6. *Lemma and palea:* The bract found in the spikelet of Grasses is known as *lemma* and the bracteoles are called *palea.* Each spikelet bears at its base two scaly bracts called glumes.

7. *Epicalyx: In Hibiscus rosasinensis,* a whorl of sepaloid green bracteoles occur just below the calyx and is called epicalyx.

Thalamus

The thalamus is that part of the flower stalk to which the floral parts are attached. It has four nodes on which four whorls of floral parts are attached. The internodal parts of the thalamus is very much condensed.

In a few plants thalamus is modified in various ways. (Fig. 5.4)

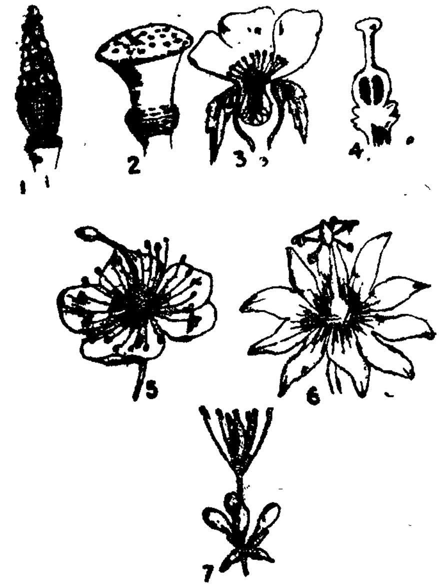

FIG. 5.4 Thalamus modifications
1. Elongated 2. expanded 3. cupshaped
4. Disc 5. Gynophore 6. Androphore
7. Gynandro phore

In *Michelia champaka* the thalamus is elongated and cylindrical where the floral parts are attached.

In *Nelumbium speciosum* the thalamus is a large expanded structure, with a flat top having numerous pits in which separate carpels are seen. In Rose, the thalamus is deeply cup shaped. In the genus *Citrus* the thalamus is flattened into a thick cushion like structure called *disc.*

In a few cases the thalamus gets elongated between the whorls of floral leaves.

(a) In *Passiflora* the thalamus elongates between the corolla and the androecium, so that the stamens are carried away from the petals. This elongated thalamus is called *Androphore.*

(b) *In Capparis, the thalamus elongates between Androecium* and Gynoecium and is called *Gynophore.*

(c) In *Gynandropsis pentaphylla,* the thalamus is elongated not only between the corolla and androecium, but also between androecium and gynoecium and is known as *Gynandrophore.*

When the thalamus presents no modification, it is just a small convex protuberance above the calyx, bearing at its summit the pistil. So the level of the pistil is above calyx, corolla and androecium. The ovary is then described as *superior.* Since the other parts are below the level of the ovary the flower is described as *hypogynous* e.g., *Thespesia populnea* (Fig. 5.5)

In some flowers the thalamus becomes hollowed out into a cupshaped *structure. The pistil is situated in the centre of the* cup. The other floral parts are arranged on the edge of the cup shaped thalamus so that they are found around the pistil and so the flower is said to be *perigynous.* The other floral parts are elevated due to the growth of the thalamus which is below the level of the ovary; so the position can be described as Suprior. e.g., *Ceasalpinia pulcherrima, Delonix regia.* (Fig. 5.6)

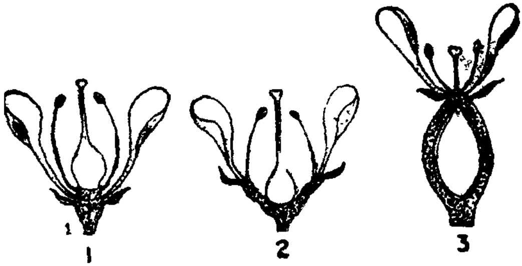

Fig. 5.5 Hypogynous flower — Fig. 5.6 Perigynous flower — Fig. 5.7 Epigynous flower

In *Psidium, Cephalandra indica,* the thalamus gets completely hollowed out and fuses with that of the ovary wall, so that the position of the calyx, corolla and androecium are brought above the ovary. So the flower is described as *epigynous* and the ovary is said to be *inferior* (Fig. 5.7).

Perianth

Perianth is a collective term for the calyx and corolla. When the components of calyx and corolla are similar in size, form and colouration, they are termed *tepals*, e.g. *Polyanthes tuberosus.* If the tepals are coloured they are said to be *petaloid* as in *Gloriosa superba.* If the colouration is dull and sepal like, they are termed *sepaloid* as in *Cocos nusifera.* If the tepals are united, they are called *gamophyllous* (*Iris*) and if they are free, they are said to be *polyphyllous* (*Allium cepa*).

Descriptive terms of a flower

1. *Chlamydeous*—with a perianth.
2. *Achlamydeous*—without a perianth.
3. *Monochlamydeous*—with only one whorl of perianth.
4. *Dichlamydeous*—with two whorls of perianth.
5. *Polysepalous*—sepals free.
6. *Gamosepalous*—sepals united.
7. *Polypetalous*—petals free.
8. *Gamopetalous*—petals united.

Aestivation: Arrangement of the perianth parts in the bud, is called aestivation (Fig. 5.8).

1. *Valvate:* Margins of segments just touching one another, but not overlapping. e.g., *Annona squama*.

2. *Twisted:* when overlapping is regular in one direction, so that one margin overlaps the next member on one side while its other margin is being overlapped by its adjacent member it is described as twisted. e.g., Corolla of *Nerium odorum.*

3. *Imbricate:* The margins of perianth lobes overlap one another in an irregular manner. One lobe is internal being overlapped on both the margins and one lobe is external.

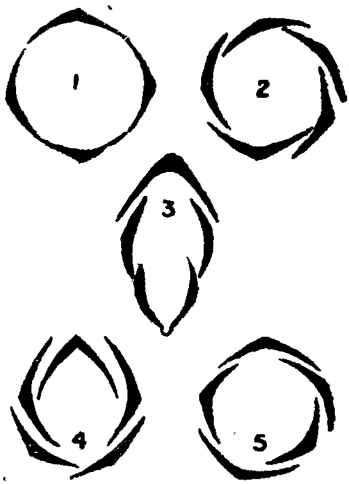

FIG. 5.8 Aestivation
1. Valvate
2. Twisted
3. Decendingly imbricate
4. Ascendingly imbricate
5. Quincuncial

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(*a*) *Descendingly imbricate:* This is characteristic of papilionaceous corolla e.g., *Crotalaria verrucosa*. Here there is a posterior large petal which overlaps the two lateral wing petals which in turn overlap the two united keel petals.

(*b*) *Ascendingly imbricate:* e.g., Corolla of *Ceasalpinia purlcherrima*. Here the anterior petal is large overlapping all the other petals.

4. *Quincuncial:* Two perianth lobes completely overlap others, while two others are completely being overlapped by others. Among the two edges of the fifth perianth one edge is being overlapped by the adjacent perianth and the other edge is being overlapped by the adjascent perianth.

Duration of the perianth

1. *Caducous*—falls away as the bud opens.
2. *Deciduous*—falls away after fertilization.
3. *Persistent*—found even in fruit.

Calyx

This is the outermost whorl of the flower and consists of sepals. Sepals are usually green and leaf like. In the bud stage sepals protect the other floral parts.

Modifications

Sometimes the sepals are modified to do certain other functions:

1. *Petaloid*—coloured and petal like as in *Petrea volubilis.*

2. *Pappus*—sepals are modified into hairy, scaly or feathery structures useful for dispersal. e.g., Compositae Family.

Corolla

Corolla is the second whorl of floral leaves composed of petals. Normally they are larger than the calyx and protect the essential organs. They are usually brightly coloured and sometimes scented so as to attract insects for pollination

When the petals are green, or have some dull colour like the sepals, they are termed *sepaloid* as in *Polyalthia.* When the lower part of the petal is narrow, it is called *claw* and its broad upper portion is described as *limb.* If the petal is with a long hollow projection it is said to be *spurred.* In some flowers like *Nerium odorum* hairy outgrowths are found on the petals and they are called as *corona.*

In the gamopetalous corolla, the lower portion is called 'tube' and the upper portion ' limb '. The upper portion is often lobed, the number of lobes indicating the number of petals in the corolla.

When the petals of the corolla are all of the same size and shape and are arranged in a symmetrical manner the corolla is *regular.* When the petals vary in size and shape and are not symmetrically arranged, the corolla is *irregular.*

Forms of Corolla

Depending upon the size, shape, structure and union of the petals, four important corolla types are recognised and under each type there are many varieties:

I. Polypetalous regular corolla (Fig. 5.9)

1. *Cruciform:* Four free clawed petals are arranged in the form of a cross as in the Cruciferae family.

2. *Caryophyllaceous:* This is formed by five free clawed petals with limbs at right angles to the claws as in the family Caryophyllaceae e.g., *Dianthus.*

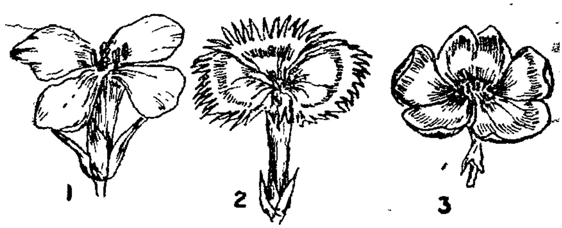


FIG. 5.9 Polypetalous regular corolla
1. Cruciform 2. Caryophyllaceous 3. Rosaceous.

3. *Rosaceous:* Corolla consists of five spreading petals, which are not clawed e.g., Rose.

II. Polypetalous irregular corolla (Fig. 5.10)

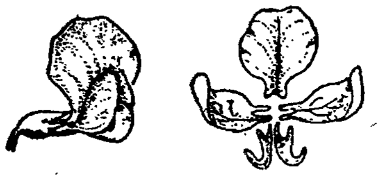


Fig. 5.10
Polypetalous Irregular Corolla
Butterfly shaped

4. *Papilionaceous:* There are five petals resembling a butterfly. The posterior petal is large and outermost and is called the *standard petal*. In addition there are two lateral *wing petals* and two anterior united *keel petals*. e.g., Papilionaceae family.

III. Gamopetalous regular corolla (Fig. 5.11)

1. *Tubular:* The corolla tube is nearly cylindrical throughout and the limbs are not spreading. e.g., Tube florets of Compositae family.

2. *Companulate or bellshaped:* The corolla is rounded at the base and spreading above like a bell as in *Physalis minima*, *Cucurbita*.

3. *Infundibuliform or funnel shaped:* The corolla resembles an inverted cone like a funnel as seen in *Datura*, *Ipomoea*.

4. *Hypocrateriform or salver shaped:* The corolla tube is long and narrow, with the limb placed at right angles to it as seen in *Vinca rosea*.

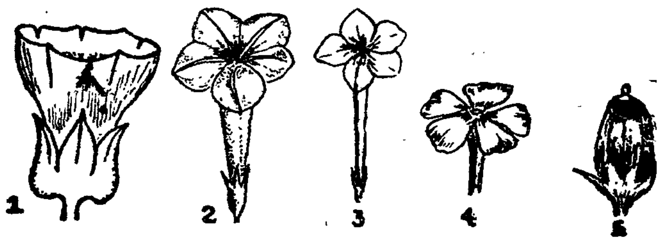


Fig. 5.11 Gamopetalous regular Corolla
1. Bellshaped 2. Funnelshaped 3. Salvershaped 4. Wheelshaped 5. Urnshaped

5. *Rotate or wheel shaped:* The corolla tube is shorter and the limbs are seen at right angles to it as in *Solanum melangena*.

6. *Urceolate or urn shaped:* Corolla tube is swollen in the middle and tapering at both base and apex as in *Bryophyllum calcinum.*

IV. Gamopetalous irregular corolla (Fig. 5.12)

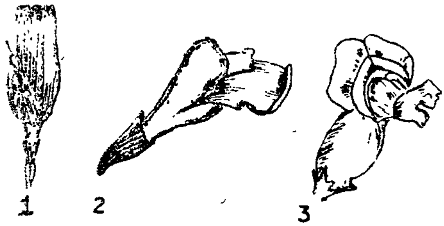


Fig. 5.12 Gamapetalous Irregular Corolla
1. Strap shaped 2. Two lipped 3. Masked

7. *Ligulate or strap shaped:* The Five petals are united to form a short tube at the base which splits on one side and becomes flattened like a strap above as seen in the *ray florets* of the compositae family.

8. *Bilabiate or two-lipped:* There are five irregular petals, united in such a way that the limb is divided into an upper posterior part formed by the union of two petals, and an unequal lower part formed by the union of three petals. e.g., *Leucas aspera.*

9. *Personate or masked:* It resembles the bilabiate corolla but the two lips are placed so close together that the mouth is closed. e.g., *Anterrhinum majus.*

ANDROECIUM

Androecium constitutes the third set of floral organs and the first set of essential organs. Androecium is composed of *stamens* or microsporophylls. Each stamen consists of a basal stalk like filament, bearing at its top *anther lobes* (microsporangia), connected by means of a special tissue called *connective*. Anther lobes contain *microspores* or *pollengrains.*

Filament

In rare cases, the stamen may be without a filament or *sessile* as in *Arum maculatum.* If the stamen is not having a fertile anther, it is *sterile* and is called a *staminode* e.g., *Cassia auriculata.* In *Canna indica* the filaments are modified into a flat expanded coloured structures and arc said to be *petaloid.* Filaments sometimes bear appendages and are called *staminal corona* as in *Calotropis:* (Fig. 5.13)

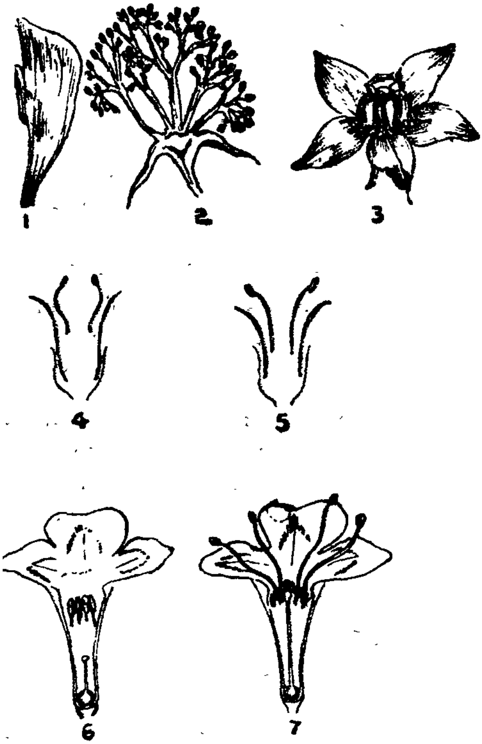


FIG. 5.13 Stamens

1. Petaloid 2. Branched 3. Staminal corona 4. Incurved 5. Recurved 6. Inserted 7 exerted

The filament may be either erect or curved. When it is curved inwards, it is said to be *incurved,* and when curved outwards it is described as *recurved.*

In some flowers, the filaments are shorter than the corolla tube, so that the stamens could not be seen outside the corolla. Such stamens are said to be *inserted* or included. When the filaments are long, so that the stamens project out of the corolla tube, they are called *exerted* or protruding.

The anther

The anther usually consists of two longitudinal lobes placed on either side of the upper part of the filament which forms the connective. The connective is attached to the back of the anther. The opposite side of the anther is the *face*, and it is always present a grooved appearance. If the faces of the anthers are turned towards the centre of the flower, the anthers are said to *introrse* e.g. *Nymphaea stellata.* But when the face of the anther is turned outwards, the anther is termed as *extrorse.* e.g., *Iris*, *Calchicum autumnale.* Rarely the anther becomes unilocular or one chambered (*Monothecous*) either by the abortion of one lobe and destruction of the partition wall between the two chambers or the destruction of the entire partition tissue separating the four chambers as seen in the family *Malvaceae.*

Attachment of the anther to the filament

The mode of attachment of the anther to the filament varies: (Fig. 5.14)

1. *Basifixed:* The tip of the filament is attached to the base of the anthers e.g., *Mustard.*

2. *Adnate:* The filament or its continuation, the connective is attached to the whole length of the back of the anther as in *Magnolia champaka.*

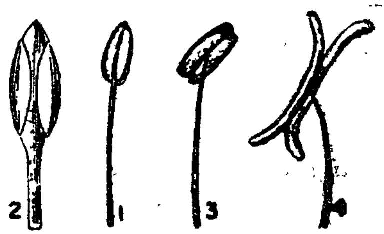


Fig. 5.14 Attachment of the anther
1. Basifixed 2. Adnate 3. Dorsifixed
4. Versatile

3. *Dorsifixed:* The filament is firmly fixed to some position on the back of the anther as in *Sesbania grandiflora.*

4. *Versatile:* Filament is attached merely at a point about the middle of the anther so that the anther can swing freely. e.g., *Grasses.*

Dehiscence of the anthers

When the anthers become mature, they burst discharging the pollen grains. This is known as *dehiscence* and the time when this takes place is called *anthesis.* Dehiscence may be of different types. (Fig. 5.15)

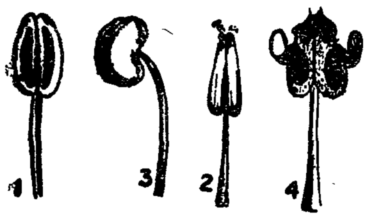


FIG. 5.15 Dehiscence of the anther
1. Longitudinal 2. Apical 3. Transverse 4. Valvular

1. *Longitudinal:* Anther lobes burst along the longitudinal slits to liberate the pollen grain e.g., *Datura.*

2. *Apical or porous:* Each lobe of the antherlobe opens at the tip by means of a small opening or pore as in *Cassia auriculatum. Solanum melongena.*

3. *Valvular:* At the top of each lobe of the anther, the wall opens like a trap door or shutter, through which pollengrains are released as in *Berberis, Laurus.*

4. *Transverse:* Anther lobe splits open transversely to release the pollengrains as in the members of Malvaceae family.

The Connective

Generally, the connective is inconspicuous so that the two lobes of the anther are close to each other. But sometimes, the connective is conspicuous.

Arrangement of Stamens

The stamens may be arranged in whorls or arranged spirally as in *Annona.* In *Eucalyptus* there are many stamens arranged in many concentric whorls. When the stamens are arranged in two whorls, they may be *diplostemonous* i.e., the outer whorl alternates with petals and the inner whorl is opposite to petals;

or *obdiplostemonous* where the outer whorl is anti petalous and the inner whorl is alternating with the petals.

On the insertion of the stamens, they may be *free* or *inserted* on the petals and are said to be *epipetalous* as in gamopetalous corollas.

Union of stamens: Union of similar parts is known as *cohesion* and union of dissimilar parts is known as *adhesion* as union between petal and stamen. Cohesion involving filaments is called *adelphy* and cohesion involving anthers is called *syngeny*. (Fig. 5.16)

Fig. 5.16 Union of stamens
1. Monadelphous 2. Diadelphous 3. polyadelphous 4. syngenesious

1. *Monadelphous:* The filaments of all the stamens are united together to form a tubular structure enclosing the pistil e.g., *Thespesia populnea.*

2. *Diadelphous:* The filaments are united into two bundles. In *Clitoria ternatea* there are ten stamens; the filaments of nine stamens are united into one bundle and the tenth stamen remains free as the second bundle.

3. *Polyadelphous:* There are numerous stamens and they are united into a number of bundles. e.g., *Bombax malabaricum.*

4. *Syngenesious:* Here the filaments are all free, but the anthers are all united so as to form a tube. e.g., *Helianthus annus.*

Length of the stamens

All the stamens of the flower may be of the same length, or of different lengths. In *Leucas aspera* there are four stamens, out of which two are longer of equal length and two are shorter of same length and is known as *didynamous*. In Mustard and Radish there are six stamens out of which four are longer of the same length, and the other two are shorter of the same size and are said to be *tetra dynamous*. (Fig. 5.17).

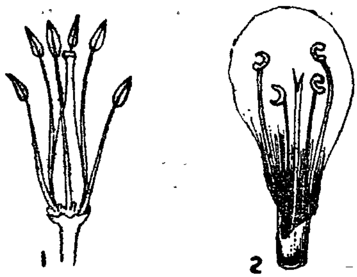


FIG. 5.17 Length of the Stamens
1. Tetra dynamous 2. Didynamous

THE GYNOECIUM

The gynoecium or pistil constitutes the fourth set of floral organs and the second set of essential organs. It consists of a basal enlarged portion called the *ovary* with *ovules* attached to the *placenta*. Above the ovary, the pistil is protruded into a long or short *style* which ends in a sticky *stigma*.

The pistil is made up of one or more *carpels* or *megasporophylls*. When there is a single carpel, the pistil is called *simple* or *monocarpellary*. If the pistil is made up of more than one carpel it is said to be *compound* or *polycarpellary*. Monocotyledonous flowers are characterised by *tricarpellary pistils* whereas Dicotyleadonous flowers are characterised by *tetra carpellary* or *penta carpellary pistils*.

In a *polycarpellary pistil* if the carpels are free from one another, it is termed *apocarpous* pistil e.g., *Annonaceae*, *Magnoliaceae*. If the carpels are united the pistil is called *syncarpous*.

The fusion of the carpels: In the syncarpous pistil, the fusion of the carpels may be complete or partial.

The Ovary

Ovary is the most important part of the pistil as it contains the ovules which develop into seeds after fertilization. A

pistil without a functional ovary is sterile. The foliar origin of the ovary is very clear from *Collutea arborescence* and *Pisum sativum.* A leaf-like carpel or megasporophyll is folded about its midrib and forms a chamber by the fusion of the margins. There is a special tissue called *placenta* along the margin and the marginal line along which the carpel fuses is called the *ventral suture,* and the midrib is called the *dorsal suture.* Ovules develop from this placental tissue and remain within the ovary chamber.

Placentation

The manner in which the placentas are distributed inside the ovary wall is called *placentation,* which differs widely in different plants. (Fig. 5.18)

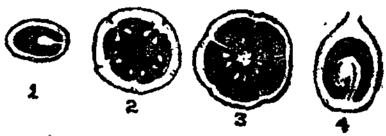


Fig. 5.18 Placentation
1. Marginal
2. Parcial
3. Axile
4. Basal

1. *Marginal placentation:* In the simple monocarpellary unilocular pistil, there is only a single placenta formed by the fused edges of the megasporophyll and situated in the ventral suture and the ovules are attached on this. e.g., *Crotalaria laburni folia.*

2. *Parietal placentation:* In syncarpous ovaries formed by the union of open carpels, the placentas are found along the inner-wall of the ovary which is unilocular. There are as many placentas as the number of carpels. e.g.. *Argemone mexicana. Passiflora edulis.*

3. *Axile placentation:* In syncarpous pistil formed by the union of closed carpels, the placentas are found at the inner angles of the cells. The number of placentas is the same as the number of carpels forming the ovary. e.g., *Thespesia populnea, Canna indica.*

4. *Basal placentation:* There is only one ovule attached to the base of the unilocular ovary e.g., *Compositae.*

The style

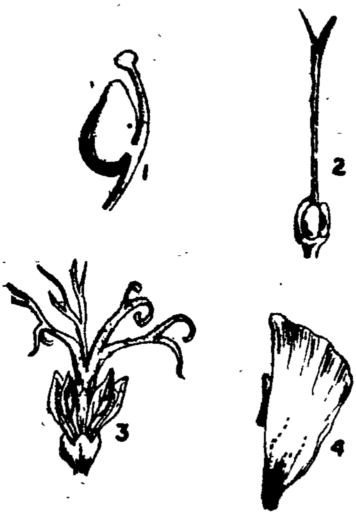


FIG. 5.19 Style
1. Lateral 2. Gynobasic
3. Branched 4. Petaloid

The style is the prolongation of the tip of the carpellary leaf beyond ovary. Usually it arises from the summit or top of the ovary and is called *apical.* Sometimes it is displaced towards one side of the ovary and is known as *lateral* or *ex-centric.* In the numbers of the family Labiatae, the pistil is syncarpous and the carpels are fused only at the base. The lateral styles are united together, so that the style is seen starting right from the base of the ovary and coming out between the lobes of the ovary. Such a style is said to be *gynobasic.* The style maybe simple or *branched* as in *Euphorbia.* It may be flattened and coloured as in *Canna indica,* and described as *petaloid.* (Fig. 5.19)

The Stigma

Usually the stigma is attached to the ovary by the style. But sometimes the style is absent as in *Poppy.* Such a stigma which

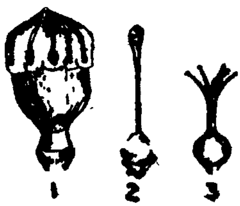


FIG. 5.20 Stigma
1. Sessile 2. Simple 3. Branched

is found directly on the top of the ovary is termed *sessile.* The stigma may be *simple* as in *Thespesia* or *branched*, the number of branches may be equal to the number of carpels as in *Sida.* (Fig. 5.20)

FLORAL DIAGRAM

Floral diagram is a diagramatic method of representing the arrangement of the floral parts in a cross section of a flower in its bud condition. It is described as a ground plan of the flower showing the relation of the floral parts to each other and to the mother axis.

In constructing a floral diagram the posterior and anterior positions of the flower has to be determined. This can be done by holding the flower in such a way that the bract is towards the observer and the mother axis away from the observer.

The mother axis of the plant is marked by a cross or well defined dot which will represent the posterior side of the flower. The bract is represented by an arc or bracket just below and opposite to the mother axis. All the parts of the flower should fall within the mother axis and bract. If there are bracteoles, they are represented on the lateral sides by means of smaller arcs.

After fixing the position of the flower Calyx, Corolla, Androecium and Gynoecium are represented one after another in concentric circles or spirals according to their disposition.

Calyx is represented as the intermost ring. Each sepal is drawn by a bracket like structure showing the midrib. The midrib of the posterior sepal (odd sepal) will be just below the position of the mother axis except in the family Papilionaceae and Monocotyledonous families:

Petals are represented next to the sepals alternating with the sepals.

In representing the sepals and petals the number and aestivation can be clearly drawn. When they are free they are left as such, but when they are united, they are jointed by means of loops.

Stamens are usually drawn in two whorls. When there are two whorls of stamens, the outer whorl is antisepalous and the inner antipetalous. When there is only one whorl of stamens, they are represented either as antisepalous or antipetalous. When there are numerous stamens, they are represented in different whorls. Monadelphous diadelphous and Polydelphous conditions can also be shown in the floral diagram by connecting the stamens according to the condition available. Epipetalous stamens are shown by means of a connection between petal and stamen.

Normally fertile stamens are shown as four locular structures. Staminode is indicated by a cross in the place where it is found.

Gynoecium is shown by the number of carpels. The syncarpous nature can be shown by the number of locules. The type of placentation and the number of ovules in each locule are also shown. Apocarpous pistil is shown by representing the carpels free from each other.

FLORAL FORMULA

It is convenient to describe a flower by means of a simple and concise formula known as the floral formula. This is meant to give an idea of the flower with the help of certain simple symbols. It supplements the information provided by the floral diagram. The following symbols are used in the floral formula.

Bractiate flower:	Br.
Bracteolate flower:	Brl.

If any one of these are omitted that means that floral part is absent in that particular flower.

Actinomorphic flower:	⊕
Zygomorphic flower:	% or ↑
Bisexual flower:	⚥
Male flower:	♂
Female flower:	♀

Calyx:	K
Corolla:	C
Perianth:	P
Androecium:	A
Gynoecium:	G

An index number in each letter is to indicate the number of parts in each whorl. For example, if it is indicated as K_5 that means that there are five sepals in the Calyx. If the numbers are enclosed within brackets to show that the parts are united. Thus $K_{(5)}$ means a gamosepalous condition. If there are 10 stamens which are united in on bundle (Monadelphous) that is known as $A_{(10)}$. Diadelphous androecium in which 9 stamens are united in one bundle and the other stamen is left free it is shown as $A_{(9)+1}$ If there are 2 whorls of floral parts of the same kind they are shown by repeating the number with a plus sign between. Thus in Radish flower there are two whorls of sepals and two whorls are stamens which are shown as K_{2+2} C_4 A_{2+4} $\underline{G_{(2)}}$. Epipetalous stamens are shown by means of a bridge connecting the corolla and Androecium

Example: $C_5 \quad A_5$.

Indefinite number is denoted by the symbol ∞ Gynoecium is represented by the letter is with its number of carpels. If the carpels are united the number is written within brackets. A horizontal line drawn either below or above the letter G represents superior or inferior ovary.

e.g., *Hibiscus rosasinensis.* Br, Brl, ⊕ ⚥ $K_{(5)}$ C_5 $A_{(\infty)}$ $\underline{G_{(5)}}$

Ixora Br ⊕ ⚥ $K_{(4)}$ $C_{(4)}$ $A_{(4)}$ $\overline{G}_{(2)}$

FLOWERS

(PHYSIOLOGY)

Factors affecting flowering

After a certain period of vegetative growth, the plant starts bearing flowers for the purpose of reproduction. The initiation of flowering is the initial stage of reproductive growth. The factors affecting the flowering are environmental and hormonal. The chief environmental factors which affect flowering are light period (photoperiod) and temperature (vernalisation).

Environmental factors

Light period: Garner and Allard found that a variety of tobacco, Maryland Mammoth, produced flowers at different times at different places. They also found that the length of the day controlled flowering in the plants.

The relative length of day and night to which a plant is exposed, is called the photo period and the response of plants to the relative length of the day and night is called photoperiodism.

Depending upon the photoperiods, the plants are classified into 3 groups.

1. Short day plants.
2. Long day plants.
3. Day-neutral plants.

Short day plants require a day length less than a certain critical length (i.e., less than 12 hours) for flowering.

Long day plants require a day length greater than a certain critical length (i.e., more than 12 hours) for flowering.

Day neutral plants flower at any day length.

1. Short day plants (Long night plants)

These plants require a relatively short day light period for flowering. In these plants, the length of the night is more important than the length of the day. These plants require a long period of uninterrupted darkness for flowering. If the dark period is less than the critical length say 12 hours, the plant

does not produce flowers even if the light period is sufficient. Flowering is inhibited even if a very weak intensity of light or even a single flash of light is given to the plant for sometime during the dark period. These plants are not capable of flowering under alternating cycles of short light and dark periods. Therefore it is evident that the length of the night and the continuity of darkness are important in initiating flowering in short day plants. These short day plants may also be called 'long night plants' e.g., Tobacco.

2. Long day plants (Short night plants)

These plants require a long photoperiod for flowering and do not require darkness. These long day plants flower best in continuous light. They are also capable of flowering in short photoperiods if they are accompanied with still shorter dark periods. In these plants, darkness has an inhibitory effect on flowering. The long day plants may also be called 'short night plants' e.g., Radish.

3. Day-neutral plants

These plants flower in all photoperiods e.g., Tomato.

Both short day and long day plants produce flowers after a short exposure to the appropriate photoperiod even if the plants are placed in unfavourable photoperiods. For example, short day plants will flower even when exposed to long day conditions, provided they have been previously exposed to a sufficient number of short days. This persistence of photoperiodic after-effect is called photoperiodic induction.

The photoperiodic stimulus is perceived by the leaves of a plant. It is found that defoliated plants are not able to flower even with proper light treatment while proper light stimulus received by even a single leaf is sufficient to induce flowering.

The red colour of the spectrum is most effective for inducing flowering. Green colour has no effect while blue colour is less effective as a flower inducing stimulus. The photoperiodic stimulus is usually due to a pigment called phytochrome.

Temperature (vernalisation)

Not all plants will flower when subjected to the correct photoperiod. In many plants, temperature has a profound influence on the initiation and development of reproductive structures. The influence of temperature on flowering is secondary to that of light. Some plants require relatively low temperature for flowering. Some require relatively high temperature while other plants flower over a wide range of temperature.

The hormonal mechanism of flowering is influenced by the temperature. It affects the rate of synthesis, the translocation and the effectiveness of the hormone in inducing floral initiation. In cold countries there are 2 types of cereals, the winter cereals and the spring cereals. The winter variety must be sown in the early autumn in order to make them flower in the following summer. If they are sown in the spring, they continue to grow vegetatively but fail to produce ears or flowers. Therefore exposure to low temperature of the winter is essential for the flowering of winter varieties.

The cold or low temperature treatment to a plant bud or seedling accelerates flowering and this phenomenon is called vernalisation. In nature the low temperature treatment is given to the annuals in the seed stage. Biennials and the perennials are vernalised at a much later stage. Vernalisation does not induce flowering but only prepares the plant for flowering. The site of vernalisation is the growing point. Sometimes the effect of vernalisation is reversible and this process is called devernalisation. A high temperature is the main cause of devernalisation.

Gibberellins favour flowering but they are different from the flowering hormone. The term vernalisation is less commonly applied to high temperature effects on the development.

Hormonal factors

Recently it has been found that flowering is controlled by a hormone called Florigen. This hormone is responsible for the initiation of flower primordia. The hormone is produced in the leaves and is then translocated through phloem to the shoot tip. The leaves are the organs which perceive the photo-

periodic stimulus and the activating agent is light. Thus if a short day plant is kept under 12 hours light period per day, it flowers in a few days. The plant does not flower when all the leaves are removed from it. If however one leaf is left intact and exposed to the appropriate photoperiod, flower formation occurs. Again, a leaf from a photo induced short day plant when grafted to non-photo induced short day plant, induces flower formation in the short day plant. Similarly, a leaf from a photo induced long day plant when grafted to non-photo-induced long day plant, induces flower formation in the long day plant. From the above account, it is evident that (1) even a single leaf, subjected to the necessary photoperiod may induce the growing points to flower (2) The Florigen or the flower hormone in both short day and long day plants, is identical in having the same properties and (3) this diffusible flowering hormone can be transmitted from one plant to another by grafting.

It has been found that CO_2 is essential for the flowering of a plant. It is supposed that a compound (A) necessary for flowering is synthesised from CO_2 during light period in the leaves. This compound (A) is then converted into a compound (B) during dark period. If the dark period is interrupted by a flash of light, flowering will not occur. From B compound, a third compound C is formed in the leaves. This C compound is responsible for the initiation of flowering. This C compound is believed to be a hormone and is called Florigen.

The application of Gibberellin to most long day plants will cause them to flower. However it is assumed that Gibberellin is not a floral hormone or at least, does not directly cause flowering. But in this group of plants there appears to be some relation between Gibberellin and Florigen. CO_2 is believed to give rise to a precursor. The precursor leads to the formation of Gibberellin like hormone which is then converted into the floral hormone, the Florigen. The process may be represented as follows.

$CO_2 \rightarrow$ Precursor $\rightarrow$ Gibberellin—like hormone $\rightarrow$ Florigen.

Sometimes nutrition may also be responsible for the flowering of plants.

Mechanism of nectar secretion

The nectaries secrete nectar. The nectaries may occur in many parts of the flower like the receptacle, petals, sepals and the bases of the filaments and pistil. Sometimes extra floral nectaries are also found. They may be formed on leaves, on stipules, on the stem, on the outside of the sepals, on bracts or on the pedicel.

Nectar is secreted (1) on the surface of the receptacle or from some part of it; (2) by the carpel walls; (3) by or in close association with the stamens and (4) by the perianth members. Secretion of nectar is influenced by the maturation of the stigma and stamens and also by the age of the flower and is usually greater on the first few days a flower is open than later. Nectar secretion in some cases is of very limited duration only.

Nectar sugars are products of photosynthesis which is influenced by sunlight. Therefore nectar secretion is greater on a sunny day than a dull day. Atmospheric pressure, soil moisture, size of nectary and position of the flower on the plant may also influence the amount of nectar secreted.

Nectar contains mostly sugar but small amounts of other substances like organic acids, volatile oils, proteins, enzymes, alkaloids etc. add to its aroma and the characteristics of the honey prepared from it. In the nectar, a mixture of sugars is present, Fructose, Glucose, and Sucrose being of regular occurrence. The total sugar concentration varies greatly and is roughly inverse to the volume of nectar excreted.

The mouth parts of the bee come together to form a tube. In the anterior part of the abdomen, the alimentary canal is enlarged into a crop or honey stomach in which the nectar is temporarily stored.

Visits by bees and other nectar gathering insects may also increase nectar secretion. Periodic removal of nectar from flowers increases the total amount of nectar and sugar secreted, although the sugar concentration is lower.

EMBRYOLOGY

Anther or microsporangium

A typical anther consists of four elongated microsporangia. It has a column of sterile tissue, called the *connective*, on either side of which is an antherlobe. When young, each antherlobe has two microsporangia. Externally, the partitions between the microsporangia can be seen as deep longitudinal grooves. Due to the breakdown of the partition between them, the two sporangia in a lobe become joined when the anther matures. In some there is only one lobe and is called *monothecous*.

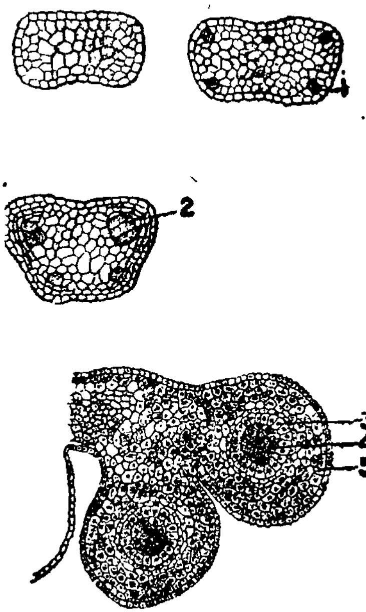


FIG. 5.21 Development of anther
1. Archesporium
2. Primary sporogenous cell
3. Tapetum
4. Spore mother cell
5. Parietal layer.

Development of Anther (Fig. 5.21)

A cross section of a very young anther shows a mass of homogenous meristematic cells surrounded by the epidermis. During its development the anther become slightly four lobed. In each lobe, rows of hypodermal cells become more prominent by their longer size, slight radial elongation and more nspicuous nuclei. These s from the *archesporium*. The extent of the archesporial tissue vary considerably both breadthwise and lengthwise.

The archesporial cells divide periclinally to form a *primary parietal layer* toward the outside and a *primary sporogenous layer* towards the inside. The cells of the primary parietal layer divide by periclinal and anticlinal walls to give rise to a series

of concentric layers, usually three to five, composing the wall of the anther. The primary sporogenous cells either function directly as the *spore-mother cells* or divide further to form a large number of mother cells.

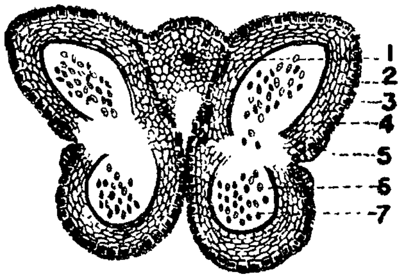


FIG. 5.22 Transverse section of mature anther.
1. Connective 2. Epidermis 3. Endothecium 4. Middle layer 5. Tapetum 6. Microsporangium 7. Microspore

Antherwall

The young antherwall comprises an epidermis followed, on the inside, by a layer of *endothecium*, 2 or 3 middle layers, and a single layered *tapetum*. They undergo the following changes at the anther matures. (Fig. 5.22)

1. *Epidermis:* Epidermis protects the tissue inside it. The cells repeatedly divide anticlinally in order to cope up with the rapidly enlarging internal tissues. In mature anther, the cells lose contact with each other and can rarely be seen at maturity.

2. *Endothecium:* This attains its maximum development when the pollengrains are to be liberated. From the inner tangential walls of these cells fibrous bands of cellose develop and run outward, ending near the outerwall of each cell. The outer tangential walls remain thin. The cellose bands may be absent in a few plants.

3. *Middle layers:* The cells of the middle layers are generally short lived. They become flattened and crushed by early meiosis in the pollen mother cells.

4. *Tapetum:* This is the innermost wall layer and surround the sporogenous tissue completely. This is of considerable physiological significance, for all the food materials entering into the sporogenous cells must pass through it. It is composed of a single layer of cells with dense cytoplasm and prominent nuclei. These nuclei may undergo some divisions at the beginning of the meiosis in the microspore mother cells. Based on its behaviour, the tapetum is of two types:

(*a*) *Amoeboid tapetum:* In this type of tapetum, the walls of the cells break down. But the protoplasts move into the anther cavity, where they unite to form a continuous mass called *Tapetal Taperiplasmodium.* e.g., *Typha*, *Tradescantia.*

(*b*) *Secretory or glandular tapetum:* The cells of this tapetum remain in their original position throughout the microspore development. This is more common among angiosperms.

Sporogenous tissue: The sporogenous cells may directly function as *microspore mother cells*, or they may undergo a few mitoses to add upto their number before entering meiosis. Each microspore mother cell produces four haploid microspores by meiosis.

Meiosis

Significance of meiosis: This is of great significance in the sexual cycle of an organism. The diploid sporophytic phase is reduced to haploid gametophytic phase by meiosis. The constancy and the continuity of the chromosome of an individual species is maintained by this division. This is also responsible for the variations due to recombinations.

The higher plants and animals contain two sets of chromosomes. They are said to be *diploid* (2n). During the gamete formation meiosis or reduction division occurs so that the gametes will have one set of chromosomes. The gametes are said to be *haploid* (n). Again during fertilization which involves the union of male (n) and female gamete (n), the diploid chromosomes are restored.

Meiosis consists of two well marked stages which are known as first and second meiotic divisions.

First meiotic division

There are four important stages namely (Fig. 5.23)

1. Prophase
2. Metaphase
3. Anaphase and
4. Telophase

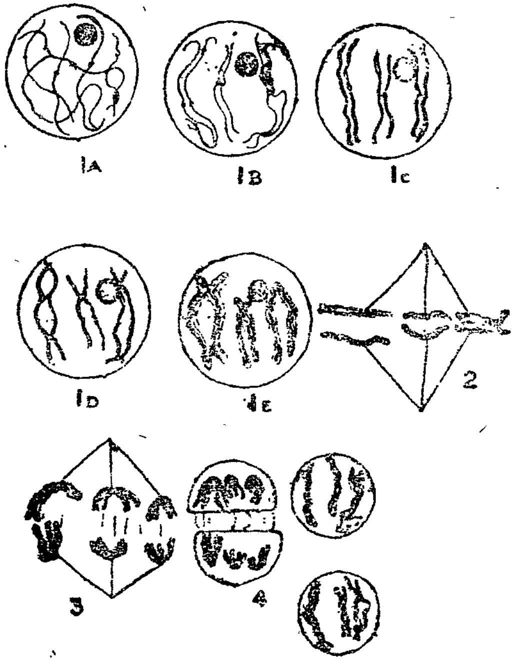


FIG. 5.23 First Meiotic Division
1. 1A-Lepotene 1B-Zygotene 1C-Pachytene 1D-Diplotene 1E-Diakinesis
2. Metaphase I 3. Anaphase I 4. Telophase I

Prophase I: Meiosis begins in a nucleus with two sets of chromosomes (2n). Most prominent and most significant changes take place during this stage. It is much prolonged and hence subdivided into five separate stages.

(*a*) *Leptotene:* During this stage the chromosomes appear as long thin filaments. There are a series of bead like structures called chromomeres seen along the length of the chromosomes.

(*b*) *Zygotene:* In this stage similar chromosomes (homologous come together closely in pairs. The pairing of similar chromosomes is called *synapsis.*

(*c*) *Pachytene:* The pairing of chromosomes is completed now. The chromosomes become thicker. Each pair of chromosome is called a *bivalent.*

(*d*) *Diplotene:* Each chromosome splits longitudinally so as to give rise to two *chromatids.* Each bivalent consists of four chromatids. The chromatids held together begin to separate in pairs. They are held together at certain points called *chiasmata* where there is a possibility of exchanging a portions of chromatids. This is called *crossing over.* The chromosomes continue to shorten actively and become coiled structures.

(*e*) *Diakinesis:* The chromosomes are more contracted at this stage. The chromosomes are detatched from the nucleolus. The chromosomes are distributed in the peripheral portion of the nucleus. The nuclear membrane and nucleolus disappear.

2. *Metaphase I:* After the disappearance of the nuclear membrane, the spindle fibres appear at the two ends. The bivalents are attached to the spindle fibres by centromeress They are found opposite to each other with the chromosome. arranged in the equatorial plane.

Anaphase I: The four chromatids are separated into two chromosomes and move towards opposite poles. Each chromosome consists of two chromatids. The chromatids form two compact groups at the poles.

Telophase I: As soon as the chromosomes reach the spindle poles they begin to get organised into nuclei. In many cases, a nuclear envelope is formed. The individual chromosomes become arranged in the new spindles. Telophase marks the end of the first meiotic division.

Second meiotic division (Fig. 5.24)

The second meiotic division is essentially amitosis. But here the chromosomes are present in haploid number and the chromatids are widely separated from each other without any coiling.

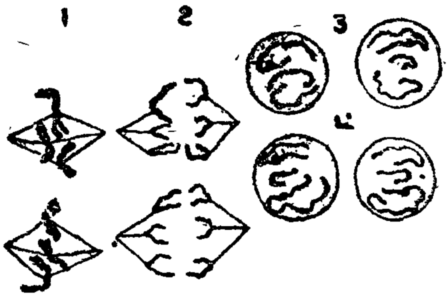


FIG. 5.24 Second Meiotic Division
1. Metaphase-II 2. Anaphase-II 3. Telophase-II

Prophase II: This stage is much simpler and shorter than prophase I. In some cases the chromatids of anaphase I reappear unchanged in prophase II.

Metaphase II: The chromosomes are arranged at the centre of the newly formed spindle fibres. The long axis of the spindle fibres will be perpendicular to the spindle axis of the first meiotic division. The centromere of each chromosome splits and becomes functionally double.

Anaphase II: As the spindle fibres contract the chromosomes move apart to the poles. The number of chromosomes reaching the poles will be haploid. There are four such groups of chromosomes.

Telophase II: The four groups of chromosomes are organised into four separate haploid nuclei (n). The nuclear membrane and nucleolus reappear again. The chromosomes are transformed into filaments which finally loose their visibility.

Cytokinesis or cellwall formation occurs resulting in four uninucleate haploid cells.

Male gametophyte.

Microspore is the first cell of the male gametophytic generation. Older microspores, after their separation as individual spores are called *pollengrains.*

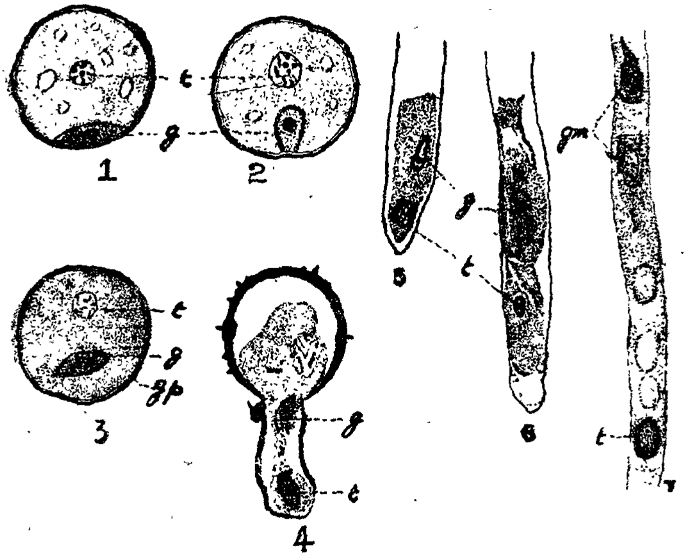


FIG. 5.25 Stages in the development of male gametophye 1 to 7.
g. Generative nucleus t. Tube nucleus gm. gametes
gp--Germpore

A freshly formed microspore in the tetrad condition is rich in cytoplasm with a prominent and centrally located nucleus. After their separation as individual spores, the microspores enlarge rapidly within a short period. During the enlargement, vacuoles appear and the cytoplasm forms a thin film inside the wall.

Development of Male gametophyte (Fig. 5.25)

Formation of vegetative and generative cells

The first division of the pollengrains gives rise to two unequal cells. The larger one is called the *vegetative cell* which eventually forms the pollentube. The smaller one is known as the *generative cell* which is attached to the wall of the pollen-

grain, but later comes to be freely in the cytoplasm of the vegetative cell.

Vegetative cell: The vegetative cell continues to grow after pollen mitosis. The cell organells increases in number as well as in size. The vacuole disappears gradually.

Generative cell: The spherical generative cell changes shape considerably to appear as a lenticular or vermiform which facilitates easy movement into the pollen tube. The cytoplasm form a very main layer with usual cell organells.

Formation of sperm

The generative cell divides mitotically to give rise to *two sperms* or *male gametes.* This may take place while the pollen grains are inside the anther, or after the release of the pollen. In the former condition the pollen are shed at the 3 *celled stage* and in the latter at the 2 *celled stage.* In those plants where pollen grains are shed at the 2 celled stage, the generative cell divides either inside the pollengrains after it has fallen on the stigma, or in the pollentube before it reaches the embryosac.

Pollen wall

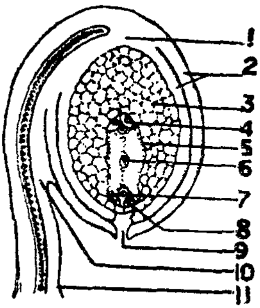
The wall of the mature pollengrain is stratified. It consists of two important wall layers, the inner one called *intine* and the outer called *exine.* The exine comprises two sublayers namely *ektexine* and *endexine.* The ektexine layer can be further divided into *tectum*, *labellum* and *foot layer.*

The intine is pectocellulosic in nature, as is the primary wall of the somatic cells. In the vicinity of the germpores of the intine, there are beads, ribbons or plates of enzymatic proteins.

The exine is composed of a special material called *sporopollenin* which is resistant to physical and biological decomposition. There are different sculpturing patterns on the exine which are proved to be of much taxonomic value.

The Megasporangium

The megasporangium or ovule consist of the nucleus and one or more coverings called integuments. It is attached to the placenta on the inner wall of the ovary by a stalk called *funiculus* or *funicle*. In the mature ovule, the integument do not completely cover the nucleus but have an opening called *micropyle*. The basal region of the ovule from where the integuments arise is called *chalaza*. Embryo sac or the female gametophyte develops in the nucleus. (Fig. 5.26)



1. Chálaza
2. Integuments
3. Nucellus
4. Antipodals
5. Embryo sac
6. Secondary nucleus
7. Egg
8. Synergid
9. Micropyle
10. Hilum
11. Funicle

FIG. 5.26 Structure of the mature ovule

Mature ovules are classified into five main types based on the position of the micropyle with respect to the funiculus. (Fig. 5.27)

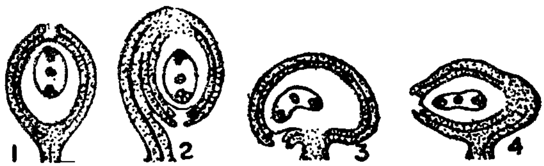


FIG. 5.27 Types of Ovule
1. Orthotropous 2. Anatropous 3. Campylotropous 4. Amphitropous

1. *Orthotropous ovule:* The micropyle and the funiculus lie in one line. e.g., polygonaceae, urticaceae.

2. *Anatropous ovule:* The body of the ovule becomes completely inverted so that the micropyle comes to lie close to the funiculus.

This is the most common type of ovule in Angiosperms.

3. *Campylotropous ovule:* The ovule is curved as in Leguminoseae family.

4. *Amphitropous ovule:* The curvature of the ovule is more pronounced and also affects the embryosac in such a way that it bends like a horse shoe. e.g., *Allium cepa.*

Integument

An ovule may have one or two integuments. Ovules with one integument are called as *unitegmic* and those with two integuments are known as *bitegmic.* The gamo petalae predominantly show unitegmic condition. Bitegmic ovules occur in poly petalae and monocots.

Micropyle

In bitegmic ovules, the micropyle is generally formed by either both the integuments or only the inner integument.

Nucellus

This is supposed to represent megasporangium. Each ovule has only one nucellus. Commonly it is covered by the integuments or integuments except at the micropyle.

Megasporogenesis

A single hypodermal cell in the nucellus functions as the *archesporium.* It becomes more prominent than its surrounding cells because of its larger size, denser cytoplasm and larger nucleus. In many plants the archesporial cell directly functions as the *megaspore, mother cell.* The nucellar tissue around it remains single layered and such a nucellus is called *tenui nucellus.* In other plants the hypodermal archesporial cell divides periclinally, cutting an outer parietal cell and an inner sporogenous cell. The parietal cell may remain undivided or undergo divisions so that the sporogenous cell becomes embedded in the massive nucellus. Such a nucellus is called *crassinucellus.* (Fig. 5.28)

The megaspore mother cell undergoes meiosis to form four haploid *megaspores*. A cell wall is laid after the first meiotic division, forming a *dyad*. A second transverse division occurs

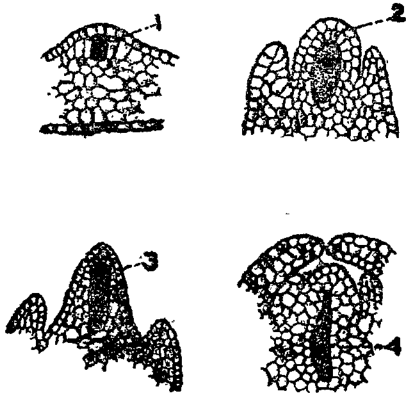


FIG. 5.28 Megasporogenesis
1. Archesporium 2. Parietal cell 3. Linear tetrad 4. Functional megaspore

in the two dyad cells so as to give rise to a *linear tetrad* of four *megaspores*. Of these, the three micropylar megaspores degenerate. The chalazal megaspore is known as *functional megaspore*.

Development of Embryosac (Fig. 5.29)

The development of embryosac begins with elongation of the functional megaspore. The elongation takes place in the micropylar chalaza axis. To begin with, the cytoplasm of the megaspore is non-vacuolate but later small vacuoles appear which may fuse together to form a large vacuole. The spindle of the first nuclear divison in the megaspore is oriented along the long axis of the cell. Wall formation does not follow the nuclear division. Between the two daughter nuclei a large central vacuole now appears and as it expands, the nuclei are pushed toward opposite poles of the cell. Both nuclei divide twice, forming four nuclei at each pole . All the eight nuclei are present in a common cytoplasm at this stage. After the last nuclear division, the cell may elongate appreciably. This is followed by cellular organisation of the embryosac. Out of the

four nuclei situated in the micropylar end of the embryosac, three nuclei organise into *egg apparatus* comprising two *synergids* and one *egg*. The fourth nucleus is left free in the cytoplasm of the

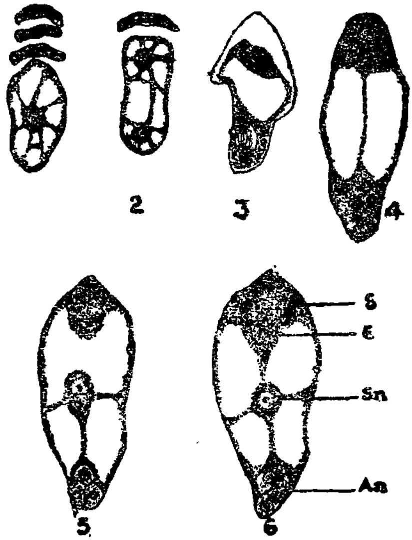


FIG. 5.29 Development of Embryosac

1. Functional megaspore 2. 2 Nucleate of embryosac 3. 4 Nucleate stage 4. 8 Nucleate stage 5. Two polar nuclei moving towards the centre 6. Mature embreyosac An- antipodal E-Egg S-synergid sn-secondary nucleus

central cell as the *upper polar nucleus*. Similarly, three nuclei of the chalazal quartet form three *antipodal cells*, and the fourth are functions as the *lower polar nucleus*. Eventually, both the polar nuclei come to lie close to each other somewhere in the centre of the embryosac and fuse into one deploid nucleus called the *secondary nucleus*. The mode of development of the embryosac described above occurs in the majority of flowering plants and is referred to as the *polygonum type*. About 81% of the families show this type of embryosac development.

POLLINATION

Sexual reproduction involves the union of male and female gametes. The male gametes are developed from the pollen-

grains (microspores) and the female gamete is developed from the embryosac of the ovule protected inside the ovary. So the next biological phenomenon is *pollination*, which means the *transference of pollen from the anther to the stigma.* Pollination is a pre-requisite to fertilisation.

Classification

Status of flowers with regard to pollination.

I Cleistogamy: Flowers do not open and are internally self-pollinated and self-fertilised.

II Chasmogamy: Flowers are pollinated in the open condition. This may be divided into two groups:

1. *Autogamy or self-pollination:* The pollen of a flower may get deposited on the stigma of the same flower. This is possible only in bisexual flowers.

2. *Allogamy or cross-pollination:* Pollen of one flower may be deposited on the stigma of another flower of the same kind. There are three kinds.

(*a*) *Geitonogamy:* implies cross pollination by another flower of the same inflorescence or the same plant.

(*b*) *Xenogamy:* implies cross pollination as between two flowers borne by two different plants of the same species.

(*c*) *Hybridisation:* is cross pollination as between two flowers borne by two plants of different varieties or species.

I Cleistogamy: In an unopened flowers, self pollination occurs in the bud condition, which then passes directly into fruit. e.g., *Viola, Oxalis, Lamium, Salvia, Commelina* etc.

II Chasmogamy

1. *Autogamy or self-pollination:* This is possible only in bisexual flowers. It is only effective if the species is self fertile e.g., *Trifolium arvense.* If it is self sterile as in *Trifolium pratense* self-pollination is ineffective and cross-pollination must occur. There are two methods of Autogamy.

a. *Direct Autogamy:* Pollen deposited directly from the anthers on to the receptive stigma.

b. *Indirect Autogamy:* Pollen has to be conveyed to the stigma by an external agent.

Autogamy is simple and direct which involves only the internal arrangements in the flower itself and is not dependant upon any agent. It occurs secondarily as a concomitant of allogamy that ensures self-pollination if the biologically preferable cross-pollination should fail.

2. *Allogamy or cross-pollination:* In nature, cross-pollination is more prevalent than self-pollination. Nature abhors self-pollination and favours only cross-pollination. The seeds produced as a result of cross-pollination are bigger, more numerous and germinate into better plants than the seeds produced by self-pollination. When cross-pollination takes place, the characters of the two parents are combined and this leads to the re-combination of new varieties of plants. Frequent self-pollination results in the gradual deterioration of the plants.

Contrivances for ensuring cross-pollination

1. *Dicliny or unisexuality:* Only in bisexual flowers there is a possiblity for self-pollination. But in unisexual flowers, self-pollination is rendered impossible.

2. *Dichogamy or ripening of sexes at different times:* In the bisexual flowers, where the anthers and stigma mature at the same time, self-pollination is possible. If they ripen at different times, self-pollination will be impossible. In some flowers like *Helianthus*, *Hibiscus* and *Leucas*, the anthers ripen before the stigma, a condition known as *protandry*. In plants like cholam, *Ficus*, and *Mirabilis jalaba*, the stigma ripens before the anthers of the same flower and this is termed as *protogyny.*

3. *Self-sterility.* In *passiflora* and *Abutilon indicum* the pollen has no effect on the stigma of the same flower. Only when it falls on the stigma of another flower pollination is effected and by this self-pollination is prevented.

4. *Pollen pre-potency:* The pollen from other flowers is more effective and grows more readily when deposited on the stigma of a flower, than the pollen from the same flower. e.g., Leguminoseae flowers.

5. *Herkogamy:* In many bisexual flowers, self-pollination is impossible because of the peculiar position of the anthers and the stigma. The anthers may be placed above the stigma, being sticky and receptive only on its lower-side as in *Vinca rosea.* Sometimes the stigma may project far beyond the position of anthers as in *Gloriosa superba.* (Fig. 5.30)

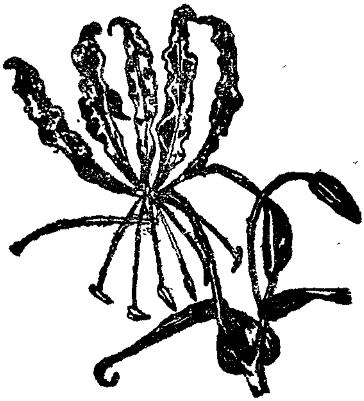


FIG. 5.30 Herkogamy

6. *Heterostyly:* In *Oxalis, Oldenlandia* and *Primula chinensis* there are two types of flowers in the same plant. In the first type the pistil is short and the stamens are situated above the stigma. In the second type the stamens are short and occupy the position of stigma of the first flower and stigma of this flower is tall and occupy the level of stamens of the first flower. Pollination occurs between the stamens and stigma of the same height. (Fig. 5.31)

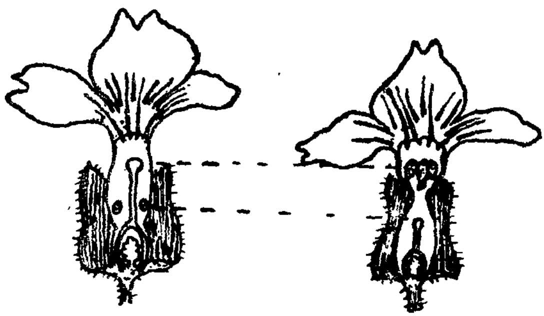


FIG. 5.31 Heterostyly

Agents of cross-pollination

During cross-pollination, pollens should be transferred from one flower to the stigma of another flower by some external forces. These are called the agents of pollination. They are

I Water (Hydrophily)

II Wind (Anemophily)

III Animals (Zoophily)

I Hydrophily or pollination by water: This occurs only in a few water plants which may occur either at the water level or below the water level.

Vallisneria spiralis is a dioecious and submerged water plant. The female flowers are solitary and are provided with stalks which bring them to the surface of the water. Each female flower has an inferior ovary and three long stigmas. The male flowers are produced in large numbers. They are released below the water and open on the surface. Their three perianth

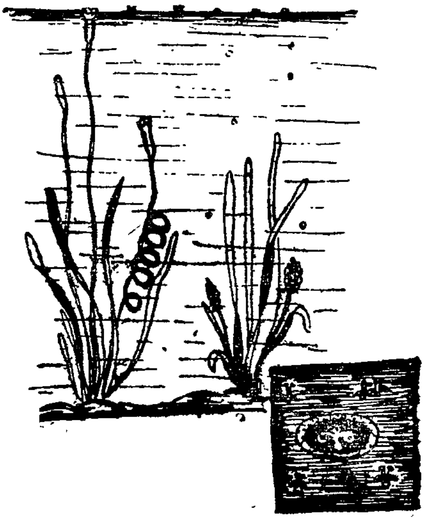


FIG. 5.32 Hydrophily

lobes open widely and are slightly recurved so that they rest on the surface of the water. The two anthers are held vertically

The pollen from both anthers cling together into one sticky mass.

The female flowers are not detached but are raised to the water surface on long spiral stalks. There they open, but as they are waxy, they are not wetted and cause a slight depression in the surface film of water. As the male flowers float about, a number of male flowers slide into the depressions around the female flowers, where they tend to tip over, bringing the pollen into contact with the stigmas. If a wave submerges the female flower, the surrounding male flowers are closely confined in a little bubble of air, thus assisting in pollination. (Fig. 5.32)

II Anemophily or pollination by wind: Wind-pollinated flowers may show certain characteristic features:

1. Plants which are situated in wind exposed region are largely wind-pollinated than those which are confined to sheltered places.

2. The flowers may be pendulous as in *Quercus* and the inflorescence may be pendulous as in *Rumex* .

3. The flowers are produced after leaf-fall, so that the pollen may be carried without interferences by the leaves as in *Odina wodier*.

4. In sedges and grasses, the inflorescence axis elongates considerably so that the flowers are brought well above the leaves.

5. Flowers are unisexual. The direction of the wind is unpredictable. The pollen grains may spread to unwanted places where the female flowers are not found. So there is lot of wastage of pollen. There are some adaptations in these flowers to meet this situation.

6. The accessary whorls of the flower namely the calyx and corolla are reduced in size and are not brightly coloured and are not scented.

7. Enormous amount of pollengrains are produced.

8. The pollen is dry, loose and powdery, so that it is easily carried by the wind.

9. The filaments are long and exserted. The anthers are versatile so that they swing freely on the filament even with a small breeze of wind.

10. The stigmas are specially adapted for catching the pollen. They are usually long and feathery and are hanging out of the flower.

III Zoophily or pollination by animals: These flowers are said to highly evolved than the other two types. There are several groups of animals which help as agents and are accordingly named.

A. Bat - Chiropteriphily.

B. Birds - Ornithophily

C. Snails - Melacophily.

D. Insects - Entomophily.

Characters found in Entomophilous flowers:

1. *Conspicuousness:* These flowers are large when solitary or found in inflorescence when small.

2. *Colour:* These flowers are usually brightly coloured. Usually the corolla is coloured and attract the insects. But the function of attraction may be also carried out by other floral parts like bracts (*Bougainvillea*) one of the sepal (*Mussaenda*) stamens (*Mimosa pudica*) and stamens and style (*Canna indica*).

3. *Scent:* Scent attracts the insects. Generally the flowers which will open during night are scented e.g. *Cestrum nocturnum.* •These flowers are white in colour which is conspicuous during darkness.

4. *Food for the insects:* In addition to the colour and scent, the flowers offer food for the insects.

(*a*) *Edible pollen:* These are called *pollen flowers.* They offer pollen as food for the visiting insects.

e.g., *Cassia marylandica*, *Anemone* and *Verbascum*.

(*b*) *Honey:* These are called *honey flowers*. These flowers offer honey for the visiting insects e.g., *Cotoneaster*, *Saxifraga*.

(*c*) *Edible sap:* In *Orchis*, juicy cells of the spur offers sap for the visiting insect.

5. The flowers open according to the nature of the insect visitor. The butterfly and bees are active during the daytime (diurnal), so these visit the flowers which open during the daytime. *Moths* are active during night (nocturnal) and visit the flowers like *Nyctanthes*, *Morinda* which open during night.

6. The pollengrains are with small outgrowth by which they can easily stick on the body of the insects.

7. The stigma is also sticky and receptive to the pollen.

8. The pollen output in these flowers are limited and so there is no wastage of pollengrains as in wind-pollinated flowers.

FERTILIZATION

During pollination, the pollengrain is transferred from the anther to the stigma. The female gamate is far away from the stigma. The pollengrains germinate on the stigma and put forth pollentubes which grow through the style and reach the embryosacs inside the ovule.

Pollen germination and pollen growth

Normally only one tube develops from one pollengrain. Sometime many pollentubes are developed as in Althea rosea. The stigma provides the pollen with necessary water and medium for its germination. The pollentube emerges at a germpore on the pollengrains. The entire contents of the pollengrain move into the tube. As the tube grows through the style, its cytoplasm is restricted to the apical region. Callose plugs are formed at successive intervals to cut off the apical region from the back region.

Path of pollen tube: The pollentube grows on the stigmatic papillae and reaches the intercellular spaces of the stigmatic tissue. Then the pollentube grows along the 'conducting tissue'

of the style. It always grows in the intercellular space and towards the direction of the ovary.

Entry of the pollentube in the ovule: After entering the ovary, the pollentube finds its way into an ovule. Depending on the position of pollentube entry into the ovule, fertilization is of three types.

1. *Porogamy*: The pollontube enters through the micropyle.

2. *Chalazogamy*: The pollentube enters the ovule at the chalazal end.

3. *Mesogamy*: Pollentube enters the ovule through the funiculus or through the integuments.

Entry of pollentube into the embryosac: Pollentube always enters the embryosac at the micropylar end. The pollentube usually enters directly into one of the synergids which has begun to degenerate even before the pollentube reaches it.

The pollen discharge: The pollentube discharges two sperms, the vegetative nucleus and a portion of cytoplasm. The two sperms change their shapes. They are true cells, each surrounded by a plasma membrane.

Double fertilization: The sperms are released in the synergid as intact cells, but only their nuclei migrate out of it. One sperm comes into contact with the plasma membrane of the egg and the other with the secondary nucleus. Fusion of the egg nucleus (female gamete) with sperm nucleus (male gamete) is called *syngamy* and the fusion product is known as zygote which gives rise to the embryo. The other sperm (male gamete) fuses with the secondary nucleus to give rise to the *primary endosperm nucleus*. This is considered to be a second fertilization and is called *triple fusion*. So fertilization in angiosperms is referred to as double fertilization. This phenomenon is unique to angiosperms.

Post-fertilization changes

After fertilization the zygote develops into the embryo which consists of one or two cotyledons and the primary axis

with a radicle and plumule. The primary endosperm nucleus divides to give rise to the endosperm. The rest of the nuclei found in the embryosac generally degenerate and disappear.

The ovary wall becomes the fruit wall and the ovule is changed into seed after fertilization. The integuments develop into seedcoats. The other floral parts namely calyx, corolla, androecium, style and stigma wither.

ENDOSPERM

Endosperm is the most common nutritive tissue for the developing embryos in angiosperms. It is the product of triple fusion and is usually *triploid*. Endosperm formation is suppressed in a few families of angiosperms.

In a few seeds like bean, pea etc., the endosperm is consumed by the developing embryo, so that the mature seed is without endosperm. It is known as *exendospermous* or *exalbuminous* seed.

Depending on its mode of development, endosperm is classified into three types.

1. Nuclear endosperm.
2. Cellular endosperm.
3. Helobial endosperm.

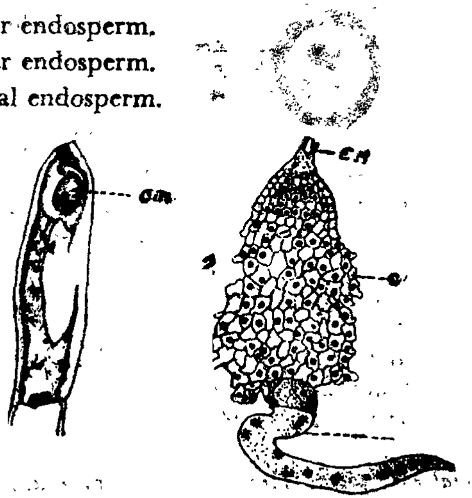


FIG. 5.33

1. Nuclear type of endosperm 2. Haustorium e-cellular endosperm em-embryo h-haustorium

1. *Nucelear endosperm:* In this type of endosperm, the division of the primary endosperm nucleus and a few subsequent nuclear divisions are not accompanied by wall formation. This results in the formation of free nuclei, which are distributed in a peripheral layer of cytoplasm surrounding a large central vacuole in the embryosac. These nuclei may be consumed by the developing embryo or more commonly, becomes cellular at a later stage. When wall formation takes place, it is from the periphery to the centre i.e., *centripetal.* The degree of wall formation varies greatly. Mostly, the endosperm becomes completely cellular. Nuclear endosperm occurs in 161 families of angiosperms.

In some plants the chalazal portion of the nuclear endosperm forms a specialised structure called *haustorium.* The haustorium gradually shrinks and disappears as the endosperm matures. (Fig. 5.33)

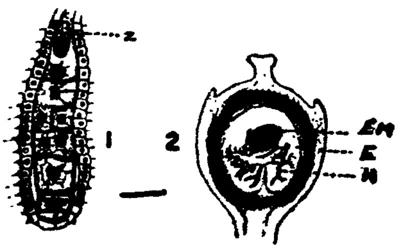


FIG. 5.34.
1. Cellulose type endosperm in Villarsia
2. Haustorium

2. *Cellular endosperm:* This is characterised by the absence of free-nuclear stage. The division of the primary endosperm nucleus and a few subsequent nuclear divisions are followed regularly by wall formation. This occurs in 72 families of angiosperms.

Haustoria occur commonly and may be micropylar or chalazal. Micropylar haustoria occurs in *Impatiens roylei.* In *Iodine rhombifolia* a very aggressive chalazal haustorium is formed. In Acanthaceae, there are micropylar as well as chalazal haustoria. (Fig. 5.34)

3. *Helobial endosperm:* Here the primary endosperm nucleus moves to the chalazal end of the embryosac where it divides to give rise to a large *micropylar chamber* and a small *chalazal chamber.* In the micropylar chamber, usually, free nuclear

divisions and cell formation take place at a much later stage. In the chalazal chamber, the nucleus either remains undivided or divides only a few times. This type of endosperm mainly occurs in 14 monocotyledonous families of angiosperms. (Fig. 5.35)

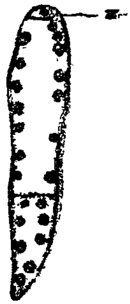


Fig. 5.35 Helobial type of endosperm

Z=Zygote.

Ruminate endosperm

If the mature endosperm is irregular and uneven in its surface contour, it is called ruminate endosperm. Rumination may belong to any one of the endosperm types described above. This is known to occur in about 32 families of angiosperms like Annonaceae, Dipterocarpaceae, Araceae etc.

Ruminate endosperm may be due to the activity of the seedcoat. The irregularities on the inner surface of the seedcoat may arise by unequal elongation of any one layer of the seedcoat or due to the unfolding of the whole seedcoat. Later on the endosperm grows and occupies the irregular inner surface formed earlier by the seedcoat.

Food materials found in endosperm

Endosperm cells store large quantities of food materials. If it stores starch, the endosperm is known as *mealy;* if it stores oil, it is described as *fatty*. In cereals, there is a definite layer of aleurone cells which contain protein, carbohydrates etc.

Functions of endosperm

1. The food materials stored in the endosperm is utilized for the growth of the seedling until it manufactures its own food.

2. Endosperm provides nutrition for the embryo during the early stages of development.

Embryo

The zygote has a period of dormancy which varies with different species.

The first division of the zygote is transverse in the majority of the angiosperms. This results in a small apical cell (*ca*) toward the interior of the embryosac and a large cell (*cb*) toward the micropyle. This is referred to as the 2-celled stage of embryo.

Proembryo

From the 2-celled stage, until the initiation of cotyledons, the embryo is called *proembryo.*

Embryogeny in Dicotyledons

The plane of division of the apical cell in the 2-celled proembryo, and the contribution of the basal cell (*cb*) and the apical cell (*ca*)lead to the formation of the different parts of the embryo which varies in different angiosperms.

The development of embryo in a plant belonging to the family Cruciferae is given below. (5.36)

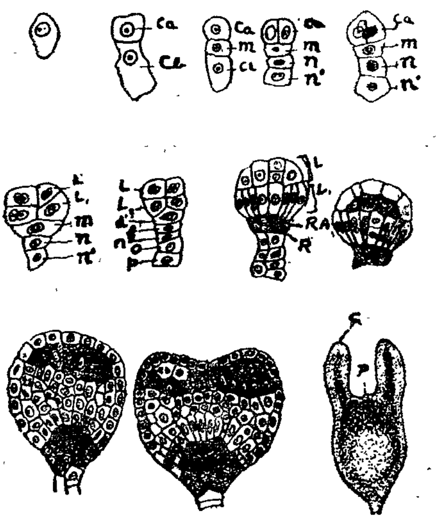


FIG. 5.36 Embryogeny in Dicotyledons

The first division of the zygote is *transverse*, resulting in a small apical cell (*ca*) and a large basal cell (*cb*) The basal cell divides transversely into two cells *ci* and *m* arranged one

above the other. The apical cell *ca* divides vertically giving rise to two juxtaposed cells. Thus a T-shaped proembryo is formed. The cell *ci* divides transversely giving rise to two cells *n* and *n'* which again divide to form a linear suspensor of 3 or 4 cells. Its derivatives divide by a vertical division to form 4 to 6 cells. Oblique periclinal division occurs in these cells resulting in an inner set of cells (the initials of root apex) and an outer set of cells (the initials of root cap).

Meanwhile, the daughter cells of the apical cell *ca* divide by another vertical division at right angles to the first division forming a quadrant *q*. The quadrant cells divide transversely to produce an *octant* made up of two tiers *l* and *l'* of 4 cells each. The cells *l* and *l'* divide and give rise to a globular mass of tissue. The peripheral cells of the globular proembryo divide periclinally to demarcate a single layer which form the protoderm. Cells of the tiers of the *l* differentiate the initials of *plumule* and the two *cotyledons* which flank on

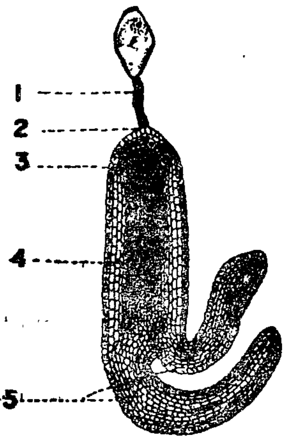


Fig. 5.37
Mature Dicot Embryogeny

1. Suspensor
2. Root-cap
3. Radicle
4. Hypocotyl
5. Cotyledons

either side of the plumule. The cells of the cotyledonary zone divides more rapidly than that in the plumular zone. Consequent on this, the plumule is enclosed at the base of the two cotyledons in the mature embryo. The tier *l'* finally gives rise to the hypocotyl-radicle axis. (Fig (5.37)

Embryogeny in Monocotyledons

Dicotyledonous embryo consists of two lateral cotyledons and the monocotyledonous embryo consists of only one terminal cotyledon. The development of embryo upto the octant stage is similar in Dicotyledons and Monocotyledons.

Najas lacerata is described here to illustrate the development of monocotyledonous embryo. (Fig. 5.38)

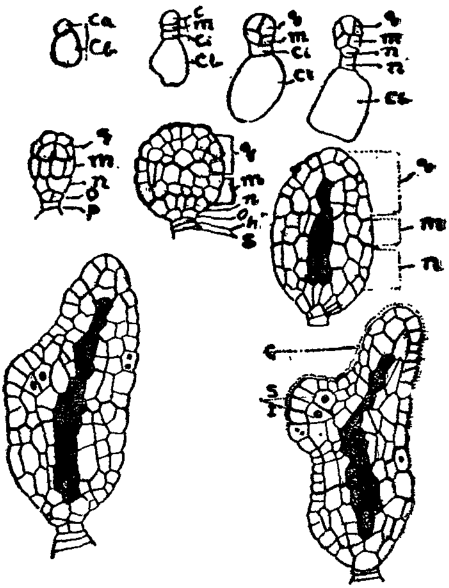


FIG. 5.38 Development of Monocot Embryo

The first division of the zygote is transverse, resulting in a large basal cell *cb* and a small apical cell *ca*.

The basal cell enlarges to form a single celled suspensor or haustorium. Thus the entire embryo is derived from the apical cell. The apical cell divides transversally into two cells *c* and *d*. Of these the cell *d* divides transversely once again. In this way a linear proembryo of four cells (*c*, *m*, *ci*, *cb*) is formed. The two distal cells (*c*, *m*) divide by two vertical divisions at right angles to each other so as to form two superposed tiers *q*, *m*, of four cells each. In the meanwhile, cell *ci*

divides transversely to give rise to *n* and n^1. The cell *n* divides vertically whereas cell n^1 divides transversely giving rise to two cells *o*, *p*.

The cell *p* divides again transversely producing *h* and *s* cells.

The quadrant *q* divides by a periclinal division cutting a four-celled protoderm surrounding the four axial cells. The cells in the tier *m* divide by vertical and transverse divisions and become two tiered. Now the pro-embryo looks slightly spherical. The cells of the tiers *m* and *n* divide transversely so that the proembryo elongates appreciably when embryo becomes oval, the central core of cells in the tiers *q*, *m* and *n* differentiate into plerome initials.

4 axial cells and four circum axial cells constitute the eight celled stage of the tier *q*. Out of the 4 axial cells, 3 of the axial cells divide faster than the fourth one. This disturbs the symmetry of the proembryo, and its top becomes notched. The cells of the tier *q* divide rapidly so as to give rise to the single cotyledon. The cells of the fourth axial cell divides slowly and gives rise to the initials of *epicotyl*. The derivatives of *n* are organised to give rise to *radicle*. Ontogenetically the single cotyledon and the epicotyl are distinctly terminal structures in *Najas*.

Parthenocarpy

Formation of fruit without fertilization is known as *parthenocarpy*. Parthenocarpic development of fruit may require pollination stimulus or it may occur in unpollinated flowers also. Since parthenocarpy does not involve fertilization, the fruits developed will be without seeds. There are three types of parthenocarpy.

1. *Genetical parthenocarpy:* Cultivated fruit trees show seeded as awell as parthenocarpic (seedless) varieties. In *citrus* an axillary branches may produce seedless oranges due to the *mutation*. Such genetic parthenocarpy all so occurs in *Punica*, *Musa*, *Cucurbita* etc.

2. *Environmental parthenocarpy:* Variations in environmental conditions such as low temperatures, fog and frost, interfere with the normal functioning of sex organs and bring about parthenocarpy. Heavy fog in the month of June caused the formation of seedless olives. Low temperature and high light intensity may lead to parthenocarpic fruits in tomatoes.

3. *Chemically induced parthenocarpy:* Many plants with seeded fruits may be made to produce parthenocarpic fruits by treatment with auxins and gibberellins at low concentrations. These substances are applied to flowers in the form of lanolin paste or sprays. Such parthenocarpic fruits include strawberry, blackberry, tomato, fig etc. The auxins used are Indole acetic acid, Indole butryric acid, Gibberellic acid, Naphthalene acetic acid etc.

Parthenocarpy increases the edible portion of the fruit. Seedless fruits are more relished than the seededfruits. So parthenocarpy finds an important place in horticulture.

Seed-coat

The main parts of a seed are embryo, endosperms and seed-coat. Details regarding the embryo and endosperm have been already dealt with.

Seed-coat: As the ovule develops into seed, the integuments mature into seed-coats. During this, the integuments undergo significant histological changes. In ovules with two integuments, the seed-coat may be derived from both the integuments or the inner integument may be lost (cotton) and the seed-coat may be formed by the outer integument alone (Cucurbitaceae). The inner integument degenerates.

The mature seed-coat is differentiated into five zones from outside inward:

1. *Epidermis* (l_1): It is made up single layer of cells which show rod like thickening on radial walls.

2. *Hypodermis* (l_2): It is 2-10 layers thick, depending on the species. The cells are thickwalled. The innermost layer is made up of radially elongated cells.

3. *Mechanical layer* (l_3): It consists of narrowly elongated osteosclereids.

4. *Aerenchyma* (l_4): It is 2-3 layers thick on the sides but more in thickness at the margins and ends.

5. *Chlorenchyma* (l_5): It consists of 10 to 12 layers of tangentially elongated cells.

The first 3 layers (l_1-l_3) are derived from the outer epidermis of the outer integument and layers l_4 and l_5 form the remaining tissue of the outer integument. In dry seeds l_4 and l_5 layers are detached from the main seed-coat and form the inner membranous coat.

Fruit development

In flowering plants, the development of the fruit is normally the effect of pollination and fertilisation. The primary effects of fertilisation are the formation of the embryo and the endosperm in the seed. In the majority of flowering plants, the subsidiary effects are the transformation of the ovule into the seed and the ovary into the fruit.

The growth regulating substances essential to fruit development are synthesised in the fertilised ovules. The sepals and sometimes also the petals synthesise growth hormones like auxins and export them to the developing fruit. The fertilised ovules induce the growth of the tissues around them into fruits. This is well known from the following observations.

(1) If all the fertilised ovules are removed, the growth of the fruit is stopped. However in some cases as in ' seedless ' grapes, development of fruit takes place even without the presence of viable seeds.

(2) The removal of some of the seeds results in the formation of mis shapen fruits. Mis shapen fruits also result from selective pollination i.e., by placing the pollen on only one side of the stigma.

Role of seeds in the growth of fruits

The importance of seeds to fruit development suggests a controlling influence of growth hormones liberated by the seeds. The seeds contain growth hormones like auxins and gibberellins. Extracts of seeds stimulate growth in unpollinated ovaries. This shows that the developing seed controls the growth of the surrounding fruit tissues through chemical substances.

Gustafson in 1936 demonstrated that in some species, application of auxin to unpollinated flowers led to the development of seedless fruits. This opened the way to certain horticultural applications and a number of synthetic growth substances are now used to set certain fruits without the help of pollination and seed development.

Effect of growth substances on fruit formation

Fruit growth depends upon growth substances. For example (1) Gibberellins influence fruit development in several ways; they stimulate pollen germination and the growth of the pollen tubes; they induce the parthenocarpic development of fruits. (2) Auxins control fruit drop.

The development of fleshy fruits involves considerable accumulation of organic metabolites (organic acids, sugars) into the succulent pericarp and associated tissues.

Seedlessness and parthenocarpy

Fruit formation may sometimes occur without seeds. This may happen in several ways.

(1) The flower is pollinated normally followed by fertilisation. However, after sometime, seed development stops and the resulting fruit contains only aborted, inconspicuous seeds as in some grapes.

(2) The flower is pollinated and the pollen germinates but fertilisation fails. Germinating pollen grains can stimulate fruit growth without actual fertilisation of the ovules.

(3) Inviable or even dead pollen may stimulate fruit formation.

(4) No pollination occurs at all, as in the cultivated banana.

In all these cases, the mature fruits are without seeds. Seedlessness differs from parthenocarpy which is defined as "the formation of a fruit without the fertilisation of ovules." Nowadays, a method has been devised by which fruits are developed by artificial culture of ovaries.

Storage of fruits and seeds

Storage means keeping the harvested fruits till they are disposed off finally to the consumer. There are different methods of storing fruits.

(*a*) Fruits are kept by *quick freezing*. In this, fruits are stocked in small packages, the temperature is suddenly made to fall below 5°F and the fruits are kept at that temperature till they reach the consumer. This method requires elaborate and costly equipment for storing, transporting and distributing fruits to various centres of consumption and so of no practical value to us at present.

(*b*) *Cool storage:* Another method of storing fruit is by cool storage. This is of several types. Common storage adopted where refrigeration is not used. Fruits are stored at room temperature. This is universally adopted in the country.

One defect with this is that temperature is not controlled in this. But it is possible to effect such lower temperature in the common orchard stories especially by providing the store rooms with better insulation and ventilation. The principle adopted is to introduce into store room cooler night air and retain it in the room, the following day.

(*c*) *Cold storage:* This is otherwise known as refrigeration method. Fruits packed in standardised boxes or other containers are stored in a refrigerated room.

(*d*) *Gas storage:* In this method fruits are stored in a mixture of gaseous medium. The principle involved in this pro-

cess is that fruits deteriorate in storage because of respiration (internal breaking down). By retarding respiration to a certain extent by providing a medium unfavourable for quick respiration at certain temperature, it has been found possible to keep the fruits in store for a long time. For example, a mixture of 5% carbon dioxide and 16% of oxygen is best for storing certain varieties of apples at 36° F. Gas storage is said to cause surface scald in fruits. This can be avoided by providing better kind of wrapper to fruits.

General precaution to be taken in all these methods of storage is that fruits should be picked without bruises. All diseased or damaged fruits should be rejected and healthy and sound fruits alone should be packed and kept in stores. Otherwise spoilage will be enormous.

Fruits kept in cold storage should be eaten immediately after they are removed from storage chamber. After removal they do not keep so well as freshly harvested and unstored fruit for more than a day or two.

Storage of seeds

Seeds are stored to protect them from birds, insects, rodents and micro-organisms and also for use during the periods of scarcity of food.

One of the primary problems of seed storage is the question of how long the seeds can be stored and remain viable. Seeds can be stored for a good number of ears. In the early times, farmers used claypots, woven baskets or even holes in the ground to store the seeds. The seeds were first dried in the sun and then stored. More common practice was the storing of seeds in a crock or basket and hanging them from ceiling directly over the oven. In this way the seeds are kept dry and also free from the attacks of pests.

Factors affecting seed longevity

Seed moisture and temperature are two of the most important environmental factors affecting seed longevity.

The lower the temperature, the longer will be maintenance of germinating capacity by the seeds. Temperature can be controlled by proper ventilation, insulation and refrigeration.

The lower the seed moisture content, the longer are the chances of longevity for the seeds. This control can be achieved by ventilation, moisture proofing, use of sealed moisture proof containers or use of desiccants.

Storage life of seeds varies according to the species and environmental conditions. While storing seeds for longer periods, it is but necessary to avoid conditions which are favourable for respiration and enzymatic action and this can be achieved by controlling moisture, temperature and oxygen availability.

The optimum temperature for longterm seed storage lies in the range of—18 to 0°C. Moisture and temperature are interrelated; if one is high, the other must be low to ensure seed viability. However, for many seeds, a temperature between 0 and 10°C and a relative humidity of 50 to 60% are sufficient to maintain full viability for a minimum period of one year.

It is possible to prolong the storage life of seeds by controlling the storage atmosphere. Respiration is decreased by reducing the oxygen content and increasing the CO_2 content. The atmosphere in sealed containers is replaced with an inert gas such as nitrogen which can prolong the storage life of some seeds.

The long term storage of agricultural seeds offers a number of advantages. The most important of them is that it permits regulation of supply and demand. Long term storage is essential for breeding and experimentation purposes. Further more, there are also biological advantages. For example, certain diseases can be controlled by using old seeds because seed borne pathogen having a short span of life can be eliminated.

Economic importance of flowers

Flowers are chiefly cultivated for their beauty as ornamentals. There are various colours of flowers to satisfy tastes

of different people. Some of the flowers are cultivated for extracting the essential oils, medicine, etc.

1. All the Hindu religious ceremonies are celebrated only with flowers. Gods are decorated with garlands made of Jasmine, Rose, Oleander and Chrysanthemum. All the festivals and marriages are celebrated only with flowers. Indian women are fond of adorning their hair with flowers.

2. Aromatic oil present in petals of flowers are extracted and used in making perfumes, cosmetics and soaps.

Scent is prepared from the petals of rose flowers (Otto of roses), *Citrus aurantium*, (Neroli) *Viola odorata* (violet), *Jasminum glandiflorum* (Jasmine oil), *Michelia champaka* (Champaca).

3. Some of the flowers are taken as vegetables e.g., Plantain flowers, Moringa, Cauliflower.

4. *Dyes:* Dyes are extracted from the flowers are *Carthamus tinctorius*, *Butea frondosa* and *Cedrela toona*.

5. *Medicines:* (*a*) *Santonin* is extracted from unopened flowers of *Artemesia cina* and is much used to remove worms from the intestines.

(*b*) Clove oil is prepared from the dried flower buds of *Eugenia caryophyllata* which is used as a medicine to relieve the pain due to tooth ache. It is also used in microtechnic and preparation of stains.

6. *Spices:* (*a*) Flower buds of *Eugenia caryophyllata* is used as a spice to give special flavour to the dishes.

(*b*) The dried stigmas and tops of styles of *Crocus sativus* are also used as a spice.

7. *Fibres:* Fibres are obtained from the inflorescence of *Sorghum vulgare ver. technicum* and are used in making brushes.

8. *Beverages:* The inflorescence axis is incised and the exudating sap is used to prepare the intoxicating drinks from coconut, palmyra etc. Gur is also prepared from this.

9. *Honey* is used as a food and medicine. Flowers secrete a sweet substance namely the nectar which attract the insects. Insects take it as a food and after partial digestion it is converted into honey.

10. *Gardens* contain different kinds of flowering plants which are cultivated for their beauty.

CHAPTER 6.

FRUITS AND SEEDS

FRUITS

Fruit can be defined as a fertilized and ripened ovary. There are two portions contained in a fruit namely the *pericarp* and the *seeds*. After fertilization the ovary wall becomes the pericarp and the ovules into seeds.

In some cultivated varieties of Orange, Grapes and Guayanas, the flower is made to give the fruit without fertilization. Such fruits are usually seedless and are known as *parthenocarpic fruits*.

When the ovary part of the flower becomes a fruit, it is known as a *true fruit*. When any other part of a flower such as the thalamus or the calyx also grows and forms part of the fruit, then it is called as a *false fruit* or *pseudocarp*.

When the fruit is developed from a single flower bearing a single pistil, whether monocarpellary or syncarpons, it is referred to as a *simple fruit*.

When it is developed from a single flower bearing many apocarpons pistils, then it is called an *aggregate fruit*.

When the whole inflorescence gives rise to a single fruit then it is known as a *multiple fruit* or a *composite fruit*.

Classification of fruits

Classification of fruits is given separately. Fruits whether true or false may be classified into simple, aggregate and multiple fruits.

Simple fruits

Based on the fleshy or dry nature of the pericarp, simple fruits are further classified into *fleshy fruits* and *dry fruits*. In fleshy fruits, the pericarp is fleshy, juicy and smooth. In

the dry fruits the pericarp is hard dry and rough. Dry fruits are further classified into *dry dehiscent* and *dry indehiscent fruits.* In dry dehiscent fruits, pericarp splits open and liberates the seeds. In dry indehiscent fruits, the pericarp never breaks open to liberate the seeds.

Simple fleshy fruits

Fleshy fruits are normally indehiscent and their seeds are freed only after the decay of the pericarp.

1. *Berry:* The whole fruit is fleshy derived from multi-carpellary, syncarpous ovary. There are usually many seeds as in Tomato, Grapes, Brinjal, Plantain. There are also one seeded berries that are developed from monocarpellary pistil as in Datepalm, *Artabotrys* etc. (Fig. 6.1)

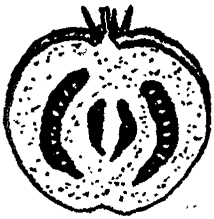


FIG. 6.1 Berry

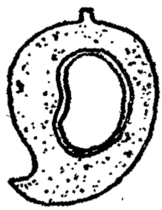


FIG. 6.2 Drupe

The pericarp is thick and succulent. It is differentiated into an outer *epicarp,* winter fleshy layer. The epicarp is thin and forms the skin of the fruit. The seeds are embedded in the inner pulp.

2. *Drupe:* (Fig. 6.2) Here the fruit wall or pericarp is clearly divided into epicarp, mesocarp and endocarp. The endocarp is hard and stony. The fruit is derived from monocarpellary or multicarpellary, syncarpous pistil. In Mango the epicarp and fleshy mesocarp form the edible portion of the fruit. In coconut, the mesocarp is fibrous enclosing a number of airspaces which is used to float in water and help the fruit in water dispersal. In *ziziphus*, there are 2 seeds inside the endocarp and the drupe fruit with more than one seed is called a *pyrene.*

3. *Hesperidium:* It is developed from superior multicarpellary, syncarpous pistil. Here the pericarp is clearly differ-

entiated into epicarp, mesocarp and endocarp. The epicarp is thick, leathery and contain oil glands. Next to it is the mesocarp which is white and spongy. The innermost thin papery endocarp forms a number of partitions which divide the fruit into a number of cells. From the inner walls of the endocarp, large number of juicy, succulent hairs are formed which constitute the edible portion of the fruit. e.g. Orange, Lemon. (Fig. 6.3)

4. *Pepo:* This is developed from an inferior, tricarpellary syncarpous pistil which is the characteristic fruit of the family Cucurbitaceae like *Cucumis sativa, Cucurbita maxima* etc. The

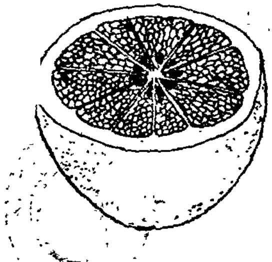


FIG. 6.3 Hesperidium

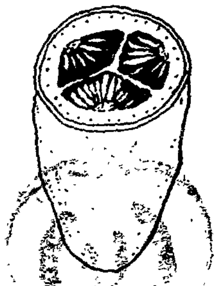


FIG. 6.4 Pepo

epicarp is thick and leathery. The mesocarp along with thick fleshy placenta are the edible portions of the fruit. (Fig. 6.4)

Simple dry dehiscent fruits

A. Fruits developed from monocarpellary pistil

1. *Legume or pod:* Here the pericarp is dry rough and hard. At maturity it splits open along both the margins and liberates the seeds e.g., Pulses. (Fig. 6.5)

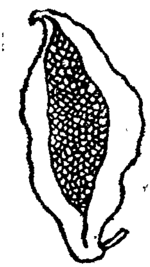


FIG. 6.5 Legume

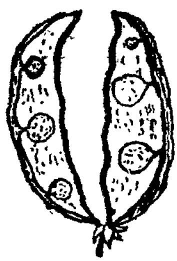


FIG. 6.6 Follicle

2. *Follicle:* In this type, the pericarp breaks along the ventral suture alone, where the seeds are attached and thereby the seeds are liberated e.g., *Calotropis, Michelia champaka, Asclepias.* (Fig. 6.6)

B. Fruits developed from syncarpous pistils

1. *Capsule:* This type of fruit is derived from multicarpellary, syncarpous pistil. There are many types of capsules variously named according to their mode of dehiscence. (Fig. 6.7)

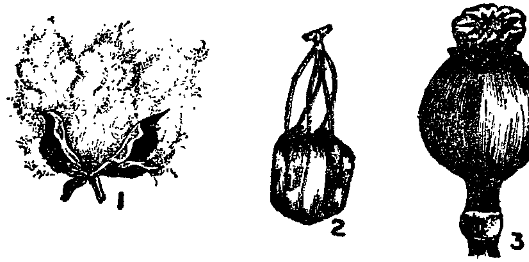


Fig. 6.7 Capsule
1. Loculicidal Capsule 2. Septicidal Capsule 3. Porous Capsule

(*a*) *Loculicidal capsule:* Here the pericarp splits longitudinally along the middle of each locule into as many valves as there are carpels and expose the seeds. e.g., *Abelmoschus esculentus*, cotton.

(*b*) *Septicidal capsule:* Here the pericarp breaks longitudi nally along the paritions or septa and liberate the seeds e.g' *Aristolochia indica.*

(*c*) *Septifragal capsule:* Here the pericarp breaks longitudinally along the locule or along the septa the valves fall away leaving the seeds attached to the central axis. e.g., *Datura, Legerstroemia.*

(*d*) *Porous capsule:* The mature fruit has got a number of small openings or pores on the top of the fruit and the seeds are liberated through them. e.g., *Papaver somniferum.*

Dry indehiscent fruits

The pericarp never breaks open. **The seeds are liberated only** after the decay of the pericarp. (Fig. 6.8)

1. *Achene:* This is developed from superior ovary. The fruit is one-celled and one-seeded. The pericarp is dry, membranous and free from the seedcoat.

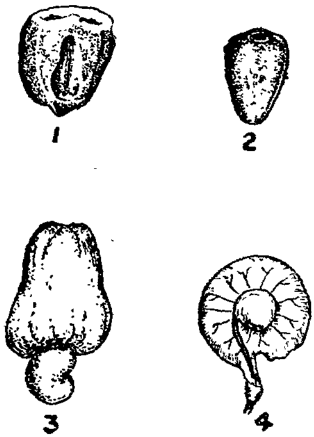


Fig. 6.8 Dry indehiscent fruits
1. Cayopsis 2. Cypsela 3. Nut 4. Samara

2. *Caryopsis:* This is also an one-celled and one-seeded fruit. The dry membranous pericarp is fused on all sides with the seed coat. e.g., Paddy, Wheat.

3. *Cypsela:* It is similar to the achene; but is developed from an inferior ovary. e.g., Tridax, Sunflower.

4. *Nut:* It is just a modification of an achene in which the fruit is large with hard, thick and woody pericarp. e.g., Cashewnut.

5. *Samara:* A winged achene is called a samara. Here the pericarp grows out into a thin winglike expansions and help in the dispersal of fruits. e.g., Pterocarpus, Acer.

Schizocarpic Fruits

A schizocarpic fruit consists of many one-seeded parts called mericarps or cocci. The fruit first breaks into one-seeded mericarps, but the mericarps enclosing the seeds remain indehiscent. (Fig. 6.9)

1. *Lomentum:* when the legume is partitioned between the seeds or constricted into a number of one-seeded parts it is called a lomentum. e.g., *Acacia arabica.*

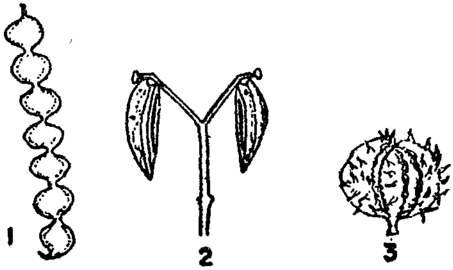


FIG. 6.9 Schizocarpic fruits
1. Lomentum 2. Cremocarp 3. Regma

2. *Cremocarp:* This is developed from inferior, bicarpellary, syncarpous ovary. At maturity, the fruit breaks into two indehiscent one-seeded fruitlets called mericarps. e.g., fruits of umbelliferal family like *Coriandrum sativum, Cuminum cyminum.*

3. *Regma:* Here the fruit first splits into one-seeded *Cocci,* then each coccus dehisces further loculicidally and liberate the seeds. e.g., Castor.

Aggregate fruits

An aggregate fruit is developed from a single flower with apocarpous pistils. After fertilization, each carpel will become a small fruit. A flower thus produces a cluster of small fruits. e.g., *Polyalthia longifolia.* In a few cases, the carpels of the flowers may unite and give rise to a single large fruit. e.g., *Annona squamosa.* (Fig. 6.10)

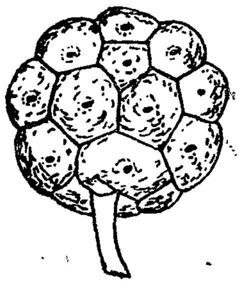


FIG. 6.10 Aggregate fruit: Annona squamosa

The aggregate fruit may be either dehiscent or indehiscent. When indehiscent, the fruit may be fleshy or dry. Thus in *Michelia champaka* the fruit is an *aggregate of follicles,* in *Clematis* an *aggregate of achenes,* in Annona an *aggregate of berries* and in Raspberry an *aggregate of drupes.*

Multiple fruits

Many flowers of an inflorescence become modified to give rise to a single fruit, it is called a multiple fruit.

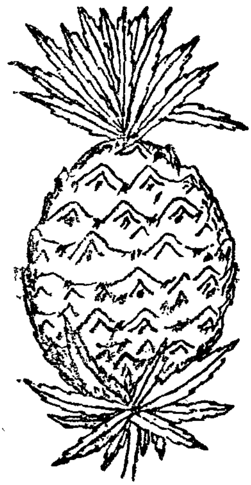


FIG. 6.11 Multiple fruit Sorosis

1. *Sorosis:* e.g., Jack fruit. The inflorescence is a unisexual spike. The female spike develops into a sorosis. The fruit consists of a long central axis which is the peduncle. The sweet edible flakes are the perianth lobes. The pericarp is baglike and contain one-cell and one-seed, the whole structure being enclosed by the perianth lobes. e.g., Pineapple, Mulberry. (Fig. 6.11)

2. *Syconus:* This fruit is developed from a hypanthodium inflorescence. The receptacle becomes the succulent and edible portion. The female flowers develop into small achenes. e.g., *Ficus carica.*

Dispersal of fruits and seeds

Generally, the fruits and seeds are disseminated away fr— the parent plant and this is referred to as dispersal. The biological significance of the phenomenon can be justified by the following points:

1. If a plant bears numerous seeds and all of them fall and germinate right beneath the parent plant, the seedlings would compete for space, water, minerals and sunlight, leading to competition and survival of the fittest.

2. When the seedlings are grouped together at one place, they could easily be detected by grazing animals and destroyed.

3. If a group of plants grow together in a limited locality, inbreeding occurs mainly, thus leading to degeneration.

4. If the seedlings are crowded together, they are much more vulnerable to epidemics like attack of fungi and insects which may lead to the complete extinction of the species.

5. Most of the plants are rooted in the soil at one place and are immobile. They are not helpful in establishing the species in a new area.

To guard against these contingencies fruits and seeds have developed many special devices for their wide distribution with the result that some of them atleast are likely to meet with favourable conditions for germination and growth. It is thus evident that the risk of a species of a plant becoming extinct is reduced to a minimum. The dispersal mechanism of fruits and seeds are as follows:

1. Autochory—where some plants have built in devices for dispersal to considerable distances. (Fig. 6.12)

Majority of the plants depend on certain external agencies such as wind, water and animals for dispersal.

2. Anemochory—dispersal by wind

3. Hydrochory—dispersal by water

4. Zoochory—dispersal by animals.

1. *Autochory:* All dehiscent fruits scatter their seeds when they burst so that the seeds are thrown for away from the parent plant. (Such fruits are called explosive fruits.) Large fruits of *Entada gigas* explode in the forests with the sound of crackers.

FIG. 6.12 Autochory

In *Ecbalium elaterium*, the content of the fruit remains under pressure and its stalk acts like a stopper. When the fruit ripens, it is detached from the stalk. The internal pressure is released and the internal contents are 'squirted' out with force upto a distance of 20 feet.

2. *Anemochory* · The fruits and seeds dispersed by wind have to be light and thin so that they float in the air for considerable distances. They are specially adapted for wind dispersal and have the following characters. (Fig. 6.13)

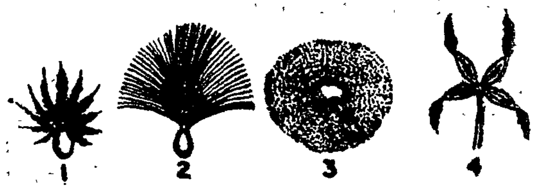


FIG. 6.13 Anemochory
1. Tridax 2. Calotropis 3. Cotton 4. Clematis

i. Very small dust like seeds are easily crried away by wind e.g., Orchid seeds.

ii. Certain fruits and seeds are provided with appendages which act like parachutes for dispersal.

(a) *Pappus* is the modification of calyx in the fruits of Compositae.

(b) *Coma* is a tuft of hair developed on the tip of the seeds to help in dispersal. e.g., *Calotropis.*

(c) Hairy outgrowths found on the seeds as in cotton.

(d) Persistent hairy style of *Clematis* and *Naravelia* help them to float in the air.

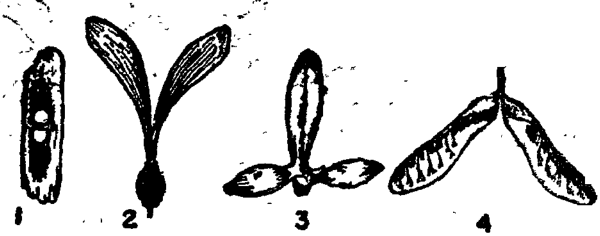


FIG. 6.14 Anemochory
1. Winged seed 2, 3, 4. Winged fruits

iii *Wings* are developed in fruits and seeds rendering them to float in the air. (Fig. 6.14)

(a) **winged seeds are seen in *Tacoma stanes*, *Oroxylum* and *Cinchona*.**

(b) Samaroid fruits are found in *Gynocarpus*, *Hiptage*, *Acer*.

3. *Hydrochory:* The fruits and seeds of the plants growing along the water side are dispersed by water. e.g., fruits of coconut, *Cerbera odollam*, Pandanus. Such fruits must be provided with a coat which is simultaneously waterproof, salt resistent and buoyant. The dry fibrous mesocarp which includes several air spaces renders them suitable for this purpose. Water lilies are dispersed by spongy thalamuses. (Fig. 6.15)

Fig. 6.15 Hydrochory Lotus

4. *Zoochory:* Some fruits are eaten by animals and the seeds are passed out with the excreta unharmed and this is called *endozoochory*. If the fruits and seeds are carried by the animals externally, sticking to their bodies or held in their mouths it is knoun as *exozoochory*.

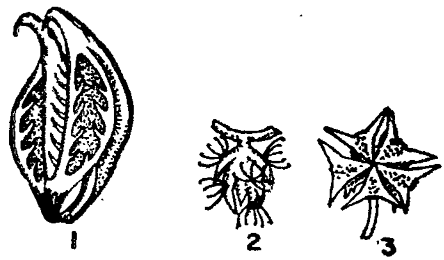


Fig. 6.16 Zoochory
1. Martynia 2. pupalia 3. Tribulus

Sometimes, fruits and seeds are provided with appendages or sticky secretions which facilitate their dispersal by animals.

1. Fruits and seeds of many plants are provided with spines, hooks, barbs or stiff hairs so that if an animal comes into contact with these fruits, they stick to their body and may be dropped far away from the parent plant. e.g., *Martynia diandra*, *Achyranthes aspera*, *Pupalia*, *Tribulus* etc., (Fig. 6.16)

2. A few fruits like *Cleome viscosa* and *Boerhaavia repens* have sticky glands so that they can stick to the body of the animals and get dispersed.

Among animals, birds are the most efficient agents because of their fruit eating habit and the long distances they travel, e.g., Plums, grapes, guavas. Dispersal by birds is known as *Ornithochory*. Bats are attracted by the odour of the fruits and disperse. Squirrels collect fruits and seeds and store them in a place very often they forget the site of hoarding and are thus dispersed.

Dispersal of seeds by ants is called *myrmecochory*. They are lured by the oily seeds of *Anemone*. After eating the oily structures, the seeds are dropped on their way and are thus dispersed.

Man has been responsible in the dispersal of several fruits and seeds. Whenever he moves in a field from one place to another, he carries the fruits and seeds without his knowledge and thus they are dispersed.

While consuming fruits like mango and citrus varieties, he takes only the edible portion of the fruit, throwing away the seeds so that they are dispersed.

Man is responsible for the dispersal of many fruits and seeds in the pursuit of more economically useful plants. Even a plant like *Capsicum fruitescence* was introduced to India by man. Plants like rubber, cinchona and eucalyptus have been successfully introduced by men and they have acclamatised well to the new surroundings far away from their original homes.

SEED

Seed is a fertilised mature ovule, consisting of an embryonic plant and protected by seedcoats. There is a great variation regarding the size, shape and colour of the seeds.

Germination

All the changes that take place from the time the seed is put in the soil to the time, a young plant is developed from it

are included under the term germination. During germination the dormant embryo is made to begin its activities with the necessary environmental and internal conditions.

Conditions necessary for Germination

A. External conditions

1. *Moisture:* Sufficient quantity of water is essential for the seeds to germinate. Seeds absorb moisture and nesume their vigorous physiological activities. The food material contained in the cotyledons or endosperm is digested and supplied to the developing embryo. Water is necessary for the digestion, respiration and conduction of the seed.

2. *Oxygen:* Oxygen is necessary to awaken the seed to respire and to begin the physiological activities.

3. *Optimum temperature:* Like all physiological activities germination is also affected by temperature. There is a *minimum* temperature to initiate the germination, an *optimum* temperature where it is most satisfactory and *maximum* temperature beyond which germination cannot take place.

4. *Light:* It has been found out that germination of 70% of seeds is favoured by light, in about 26% of seeds, light inhibits germination while about 4% of seeds are indifferent to light.

B. Internal factors

1. *Food and auxins:* All the seeds contain reserve food material either in the cotyledon or in the endosperm. Auxins are growth promoting substances essential for germination.

2. *Dormancy:* Many seeds will not be able to germinate as soon as they are discharged from the plants. They require a period of rest known as *dormancy period* which varies from species to species. This is advantageous to the plant since it enables the embryo to safely pass the unfavourable part of the year and germinate when the conditions are favourable. Seed dormancy may be due to seed coat dormancy. Hard seed coat may offer resistence to embryo growth (Malvaceae)

or it may be impermeable to water as in *Trigonella* or oxygen as in *Xanthium*. Seed dormancy may be due to *embryo dormancy* which requires certain period of time after harvesting so as to enable it to germinate.

3. *Viability:* Viability is the capacity of the seed to germinate. Seeds are viable only for a definite period of time after which the embryo becomes dead for all practical purposes. Viability of the seeds may vary from one growing season to many years according to the species. Conditions of storage, temperature, humidity, proper drying of the seed etc., determine the viability of the seeds. Agriculturists are advised to select seeds after they are subjected to yiability which is necessary to ascertain the germinating capacity of the seed.

Vernalisation

The term vernalisation has been defined by Chouard as ' the acquisition or acceleration of the ability to flower by a chilling treatment.' The term vernalisation is less commonly applied to the treatment of seeds at high temperatures or to treatment of other plant organs than seeds.

In the process of vernalisation, the seed is first soaked in water and is allowed to germinate till only the radicle has emerged. It is then subjected to low temperature treatment for an appropriate period which differs among different varieties. The seed is then dried and sown later in the usual way. By this method, the vegetative growth period of crops can be considerably reduced so as to give the yield earlier. This method is developed in Russia by Lysenko in the improvement of agricultural crops.

Changes during germination

When all the conditions are satisfied, the seeds swell by rapid *imbibition* and *osmosis* of water. This causes the seed to rupture. Absorption of water induces the physiological activities of the protoplasm. There is rapid *respiration* and copious secretion of enzymes which render the stored insoluble food in the form of simple soluble food. This soluble food is

conducted to the parts of the embryo which *assimilate* this food and begin to grow. The radicle grows vigorously and comes out of the seed through micropyle and fixes the seed to the soil. After this either the *hypocotyl* or *epicotyl* begins to grow fast when the hypocotyl grows fast first, it pushes the cotyledons to come out of the soil and the mode of germination is called *epigeal germination.* When the epicotyl grows fast first, only the plumule is pushed out of the soil while the other parts remain inside the soil. This type of germination is called *hypogeal germination.*

Structure of the Bean seed

The seed is bulky, oval and slightly indented on one side. On this side there is a longitudinal whitish ridge formed by the funicle called *raphe.* There is a small opening called the micropyle at one end of the raphe. At the other end of the raphe is the chalaza. The seed has got two seed coats outer known as testa and the inner tegmen. Inside the seed coat is the embryo. It consists of two fleshy cotyledons, attached

FIG. 6.17 Structure of the bean seed
1 Cotyledon 2. Hilum 3. Plumule 4. Radicle

to the primary axis. The primary axis has a rudimentary root portion called the *radicle* and a rudimentary stem portion called the *plumule.* The tip of the radicle points towards the micropyle. The plumule is seen in between the two cotyledons and consists of a short axis and a small bud having two tiny little folded leaves. There is no endosperm in the mature seed. (Fig. 6.17)

Germination

The seed swells absorbing moisture from the soil By the activity of the embryo, the radicle grows and comes out of the seed through the micropyle. Due to the pressure exerted by

the radicle, the seed coat is ruptured. The radicle grows into the soil and become the primary root.

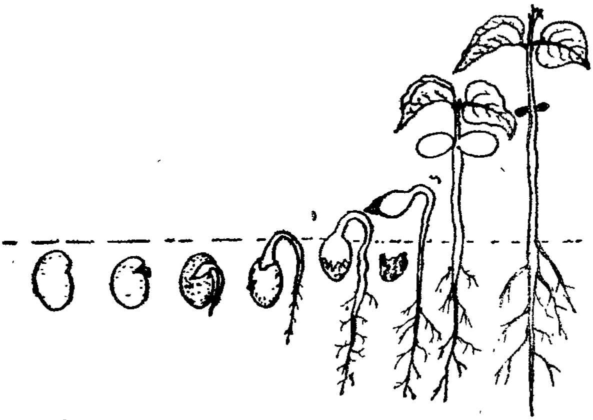


FIG. 6.18 Stages in the germination of the bean seed

The hypocotyl begins to elongate. The lower end of the hypocotyl is fixed to the soil and its upper end is attached to the cotyladons which are inside the seed coat. The hypocotyl elongates, resulting in its bending up and coming out of the soil in the form of a loop. The loop begins to grow erect and the two cotyledons are pulled out of the seed coat and brought above the soil. After coming out of the soil the cotyledons separate, spread out on either side. Now they are light green in colour and are called first pair of leaves of the seedling. The plumule now develops, absorbing food materials from the cotyledons. In the meanwhile, the primary root develops several lateral roots and firmly fixes itself to the soil. The plumule develops green leaves. The roots absorb water and mineral salts, thus becoming an independent plant. Since the cotyledons are brought above the soil level due to the growth of the hypocotyl, the germination is called epigeal. (Fig. 6.18)

Castor Seed

Structure of the Castor seed

The seed is oval in shape with two seed coats. The outer seed coat is called *testa* which is brittle and brown or black in

colour. The inner seed coat is called *tegman* which is thin and white in colour. There is a spongy outgrowth of the micropyle known as *caruncle*. Just below, tegmen there, is endosperm which is the fleshy food storage tissue rich in oil. Embryo lies embedded in the endosperm and consists of an axis with a radicle pointing towards the micropyle and an undifferentiated plumule and turn their flat leafy cotyledons with distinct veins. (Fig. 6.19)

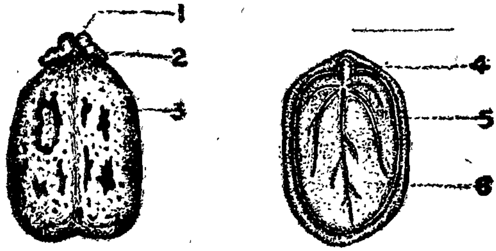


FIG. 6.19 Structure of Castor seed
1. Caruncle 2. Hilum 3. Seed coat 4. Radicle
5. Endosperm 6. Cotyledon

Germination

During germination, the caruncle absorbs water and becomes soft and enlarged. The cotyledons absorb the food materials from the endosperms and pass them on to the deve-

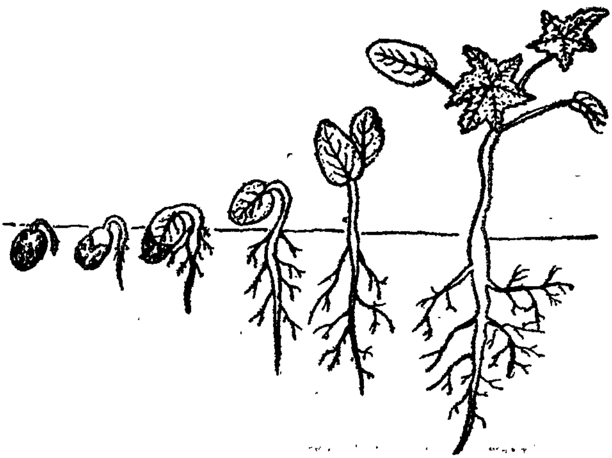


FIG. 6.20 Stages in the germination of the castor seed

loping radicle and plumule. The radicle grows and comes out of the seed first and fixed to the soil. The hypocotyle grows rapidly and forms a loop so as to bring the cotyledons above the soil. The cotyledons spread out, turn green in colour and become the first leaves of the plant. The plumule produces the green leaves and a young seedling is established in the soil. (Fig. 6.20)

Paddy

Structure of the Paddy

Paddy grain is an one seeded fruit called *caryopsis*. It is enclosed by brownish husk which consists of 4 parts called *glumes*. The two minute ones at the base are empty glumes. Out of the other two glumes, the larger one is called *lemma* and the smaller one is called *palea*.

Each grain consists of seedcoat and the wall of the fruit fused together. Endosperm forms the main bulk of the grain and is the food storage tissue. It is separated from the embryo by epithelium. Embryo is very small and lies in a groove at one end of the endosperm. It consists of only one cotyledon known as the *scutellum* which is shield shaped. It also consists of a short axis with plumule and radicle protected by the root-cap. The plumule is surrounded by a protective sheath called *coleoptile*. Similarly, the radicle and rootcap is

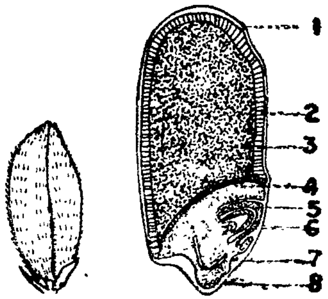


Fig. 6.21
Structure of Paddy

1. Seed coad. 2. Aleorone layer. 3. Endosperm. 4. Cotyledon. 5. Coleoptile. 6. Plumule. 7. Radicle. 8. Coleorhiza.

protected by a root sheath called *coleorhiza*. The surface layer of the scutellum lying in contact with the endosperm is the *epithelium* which digests and absorbs the food material stored in the endosperm. (Fig. 6.21)

Germination

The scutellum absorbs the food material stored up in the endosperm. The radicle grows down into the soil piercing the coleorhiza. The plumule grows out enclosed in coleoptile, pierces through the soil and comes to the surface. It then

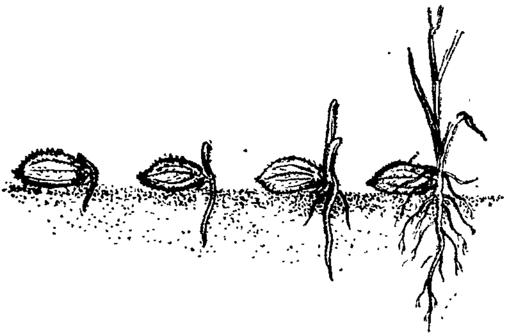


Fig. 6.22
Stages in the germination of the paddy.

bursts through the coleoptile and produces the first foliage leaf. The primary root dies out and several adventitious roots arise from the base of the young stem. Since the single cotyledons do not come out of the soil, the germination is said to be hypogeal. (Fig. 6.22)

Vivipary

Germination of the seed within the fruit while still attached to the mother plant is called *vivipary*. This is found in a number of plants. e.g., *Sechium edule*, *Cocos nucifera*. Paddy grains germinate on the mother plant, if they get sufficient moisture.

A special kind of vivipary is seen in the mangrove plants found in estuarine tidal shores of the tropics. The seed embryos in these plants do not have any resting stage and continue to grow uninterruptedly inside the fruit. First, the radicle comes out of the fruit and then the hypocotyl begins to grow very vigorously. The length of the hypocotyl varies from 2 to 18 inches according to the species and also by the depth of the water below. The hypocotyl looks like a clubshaped structure with taperingends. The cotyledons which remain inside the fruit act as haustoria and the plumule grows. When the hypocotyl grows very heavy, the fruit gets detached from the plant and falls vertically down so that the radicle penetrates the soil. It soon forms a root system and the plant is established in the soil. The plumule grows safely above the water and become the tree. e.g., *Rhizophora mucronata*, *Ceriops roxburghiana*. (Fig. 6.23)

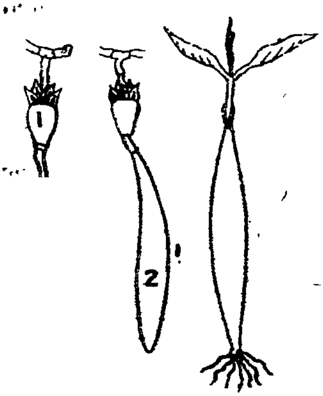


FIG. 6.23 Vivipary
1. Fruit. 2. Hypocotyl

ECONOMIC IMPORTANCE OF FRUITS AND SEEDS

Plants store their food materials chiefly in their fruits and seeds. So they are highly nutritious. Man exploit them fully. In addition to food they also provide us with oils, fibres, dyes and drugs.

Food

Cereals form the most important sources of plant food for man. They all belong to the family Gramineae.

(a) *Paddy* (*Oryza sativa*). It is under cultivation for the past 8000 years. Rice is the staple food of South Indians. There are many improved varities such as CO_{20} ADT 17,

Ponni etc., In India more than 1100 varieties are sown. Its straw is used as a cattle food.

(*b*) *Wheat* (*Triticum vulgare*): It is under cultivation for the past 6000 years. It is a staple food for the majority of Indians. There are several new varieties such as Sonora 64, Safed Lerma, Sharbati Sonora etc.,

(*c*) *Maize* (*Zea mays*). It was cultivated by Red Indians in Mexico as early as 2000 B.C. Columbus introduced this to Europe and Portuguese brought this to India. The important improved varities are Amber, Jawahar, Kissan, Sona, Vijay and Vikram. Barley (*Hordeum vulgare*), Oats (*Avena sativa*) and Rye (*Secale cereale*) are important food cereals used in western countries.

Cholam (*Sorghum vulgare*), Kambu (*Pennisetum typoideum*), Ragi (*Eleusine coracana*) are important food grains used by Indians.

Pulses are rich in proteins and therefore have important food value. They are commonly used as food. Pea (*Pisum sativum*), *Cicer aurietinum, Phaseolus vulgaris, Phaseolus aureus* (greengram), *Phaseolus mungo.*

A number of fruits are cooked as vegetables or sometimes pickled.

1. Brinjal—*Solanum melongena.*
2. Pumpkin—*Cucurbita pepo.*
3. Lady's finger—*Hebiscus esculentus.*
4. Ash gourd—*Benincasa cerifera.*
5. Chow chow—*Sechium edule.*

Fruits contain minerals and rich vitamins. So they are taken as such.

1. Apple—*Pyrus malus.*
2. Grape—*Vtis vinifera.*
3. Plantain—*Musa paradisiaca.*
4. Mango—*Mangifera indica.*
5. Orange—*Citrus aurantium.*
6. Date—*Phoenix dactylifera.*

Oil: Oil is chiefly stored up in the seeds and also to a certain extent in fruits. These fatty oils do not evaporate in ordinary temperatures. So these are called non-volatile oils. They are used in making soaps, varnishes, paints and also for cooking.

Oil from fruits

Olive oil—*Olea europaea.*

Palm oil—*Elaeis guineensis.*

Oil from seeds

1. Groundnut oil—*Arachis hypogea*
2. Castor oil—*Ricinus communis.*
3. Sesamum oil—*Sesamum indicum.*
4. Margosa oil—*Azadiracta indica.*
5. Sunflower oil—*Helianthus anuus.*

Fibres from fruits and seeds

Fibres obtained from the fruits of coconut is widely used in making ropes, carpets, door mats and brushes.

Fibres from seeds

Cotton fibres are obtained from *Gossypium herbaceous*, G. *arboreum* etc., It is the raw material for the textile industry. It is also used to manufacture tyres, explosives, rayon and cellulose.

Tannins

Tannin is extracted from the unripe fruits of *Terminalia chebula*, *Terminalia bellerica*, *Ceaselpinia coriaria.* The tannin is used in the leather industry.

Medicines

Calocynth drug is extracted from *Citrullus calycinthus* and is used as a purgative.

1. *Chaulmoogra oil:* Oil is obtained from the seeds of *Hydrocarpus kurzii* and is used in the treatment of leprosy.

2. *Croton oil:* This is obtained from the seeds of *Croton tiglium.* It is used as a purgative.

3. *Nuxvomica:* It is obtained from the seeds of *Strychonos nux-vomica.* This drug is powerful poison. In small doses it is used in medicine as a tonic and for the treatment of nervous disorders.

Spices

Spices are used in cooking and in flavouring ice creams, cakes etc.

1. Capsicum—This is got from *Capsicum frutescens* and is used in cooking.

2. Peper from the *Piper nigrum* is used as a condiment.

3. Vanilla is got from *Vanilla planifolia* fruits and is used in flavouring ice creams, chocolate etc.

4. Coriander from *Coriandrum sativum* is used for flavouring beverages.

5. Cumon from *Cumonum cymonum* used in soup, curries etc.

Seeds are also used as spices.

Cardamum from *Elettaria Cardamomum* and Fenugreek from *Trigonella foenum graecum* are used in curries.

Beverages

Beverages are substances which provide us refreshing and delicious drinks.

1. *Coffee:* Coffee is one of the most important beverages. Seeds of *Coffea arabica* are the source of coffee.

2. *Cocoa* and *chocolate* · These are prepared from the seeds of *Theobroma cocao.*

CHAPTER 7

VEGETATIVE PROPAGATION

All living organisms are endowed with the capacity of reproduction. Reproduction is the production of new ones similar to the parents. Life cycle of the plant is said to be completed only after reproduction. It is essential to continue the race on the earth.

There are two types of reproduction met with in Phanerogams.

1. *Sexual reproduction* which involves union of male and female gametes so as to produce the fruits and seeds.

2. *Vegetative propagation or vegetatative reproduction.* When new plants arise from cut portions of the old plant, the method is known as vegetative propagation. This is found in many plants and is extensively exploited in the production of many garden plants.

There are many methods of of vegetative propagation:

1. *Cutting:* In the *Moringa* or *Thespesia* plant, if a branch with nodes and internodes is cut and planted in the soil, it will develop buds and roots and become an independent new plant. The separated branch is called a *cutting.* In sugarcane only a small portion of the stem consisting of the bud and node known as '*set*' can give rise to a new plant.

2. *Layering:* In the case of Jasmine and *Nerium odorum* a portion of the plant is bent down after removing the bark and covered with soil. When this portion is watered well, it will develop into a fresh plant after a few days. Even if the portion is cut off from the mother plant, it can lead an independent life. This method of vegetative propagation is called *layering.* (Fig. 7.1)

3. *Aerial stems* Some of the weakstemmed plants like runners and stolons develop a number of daughter plants in

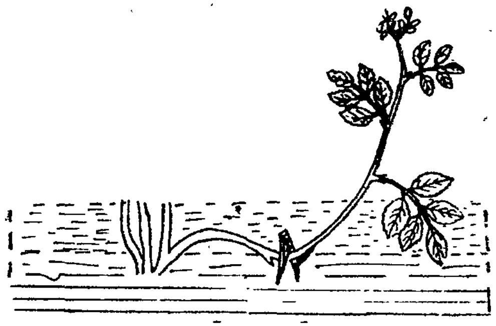


FIG. 7.1
Layering

the course of their growth and help in the vegatative propagation of these plants. e.g., *Hydrocotyle asiatica.*

4. *Underground stems* Underground stems are very useful to store large quantities of food materials safely kept underneath the soil, beyond the reach of the grazing animals. In addition to this, they are very helpful in the vegetative propagation of these plants within a short time.

Underground stems like rhizome (ginger), corm (colocasia), tuber (potato) and bulb (onion) certain axillary buds and terminal buds which help to develop into many new plants.

5. *Adventitious buds* · Normally buds are seen in plants as terminal and axillary buds. If the buds are found in any other part of the plant such as leaves, inflorescences etc. those buds are called adventitious buds. (Fig. 7.2)

(a) *Buds on roots:* In *Millingtonia, Psidium guayava, Cassia fistula* and Morgosa trees buds are developed on the roots and they give rise to new plants.

(b) *Buds on leaves:* When portions of the leaf are covered with moist soil, adventitious buds and roots arise to give rise to new plants as in *Begonia.*

In *Bryophyllum*, if the leaf is tied to a thread and suspended in moist air, adventitious buds and roots develop from the margins of the leaf which are capable of giving rise to new plants.

FIG. 7.2
Adventitious buds
1. Begonia.
2. Bryophyllum
3 Bulbils

(*c*) ***Bulbils:*** Sometimes the buds are modified into peculiar structures called *bulbils* which on separation give rise to new plants with favourable conditions.

In *Scilla* such bulbils are seen on the leaftips. In *Dioscorea bulbifera* bulbils are seen in the axils of leaves and serve for vegetative propagation. The large inflorescence of *Agave americana* shows many of its floral buds transformed into bulbils which begin to germinate while still on the inflorescence. Such transformation of flower buds into bulbils is also seen in *Allium sativum* and *Globba bulbifera.* In *Oxalis*, bulbils occur on the swollen root.

Advantages

1. New plants can be developed within a short time by different methods of vegetative propagation.

2. The characters of the mother plant is faithfully reproduced in the daughter plants obtained by methods of vegetative propagation. Even in hybridisation techniques, after evolving a new strain superior in all respects, is multiplied by vegetative propagative methods to preserve the old traits.

Disadvantage

There is no possibility of introducing new characters in the progeny in the method of vegetative propagation.

Grafting

In the cutting and layering methods of vegetative propagation, there is no possibility of improving the quality of the strain, but in grafting the quality of the existing variety can

be improved. The existing variety is known as *stock* and the superior variety is called a *scion.* The two plant portions are made to unite and the quality of the yield will be improved to that of the scion variety. There are three methods of grafting.

1. Approach grafting
2. Stem grafting
3. Bud grafting.

1. *Approach grafting:* This is a simple and largely practised method of grafting. The superior variety with which grafting is attempted is grown in the soil. The stock variety is grown in pot. When both the stock and scion reach about 1.5 cm. thickness they are brought near each other. A shallow slice of stem is removed from the stock and scion. They are brought into contact with each other and held firmly in position by means of grafting tape. The graft portions are kept moist so that the tissues are organically united. After the union is complete, the base of the scion and the top of the stock are severed below and above level of the portion of grafting. When the yield is obtained, it will have the quality of the scion. This method of grafting is practised in grafting the economically important plants like mangoes, sapotas and guavas. (Fig. 7.3)

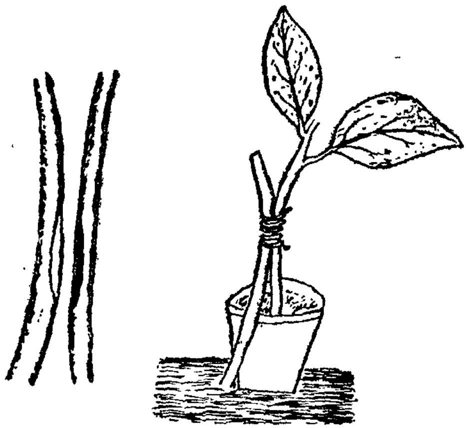


FIG. 7.3
Approach grafting

2. *Stem grafting:* The scion and the stock are selected in such a way that they are equal in thickness. The tip of the scion and stock are cut obliquely and cut surfaces are brought together by bandaging tightly with tape. Thus the stock and scion are held firmly in position. Sufficient moisture is provided in the graft portion by the application of clay or grafting

wax. This type of grafting is also known as *whip grafting*. All buds are removed from the stock but not from the scion.

3. *Bud grafting:* Here grafting is not done between two

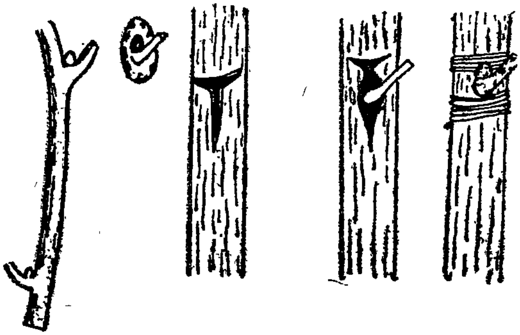


Fig. 7.4
Bud grafting

equal portions of stock and scion. It is done between the bud of a scion to the portion of the stock plant.

A portion of the stem with its axillary bud is taken as the scion. A T-shaped incision is made in the stock portion of the plant. The scion portion is placed in the incision of the stock and held in position firmly by bandaging it carefully with tape. The scion absorbs water and minerals from the stock and develops into a plant of superior variety. e.g., Apple, Orange and Rose. (Fig. 7·4)

Advantages of grafting

1. The yield is obtained earlier by grafting 5 year old portion of the scion to one year old stock. e.g., Mango.

2. The quality of the fruits and flowers can be improved.

3. Period of life of the plant can be extended by grafting portions of annuals to the perennials.

4. Better and new varieties of fruits and flowers can be obtained by grafting.

Limitations

There is one limitation in grafting namely that it possible only between closely related plants.

CHAPTER 8

GROWTH AND MOVEMENTS

GROWTH

Growth is an important characteristic feature of living things. It is rather difficult to define growth. The essential feature about growth is the production of new cells which is accompanied with an increase in size and weight. Growth is not merely an increase in size or weight of an organism. It is always accompanied by a process called development, which involves a progressive change in form. i.e., production of leaves, branches, flowers etc. Therefore growth may be defined as a permanent and irreversible increase in size and form of an organism accompanied by an increase in dry weight.

Growth in plants is generally restricted to regions of growing points called meristems. The apical meristems present in the root apex and the shoot apex are responsible for growth in length. In certain plants like grasses, increase in length is also due to intercalary meristems present at the nodes. Growth in thickness is brought about by the lateral meristem namely cambium.

Stages of Growth or Phases of growth

Growth of any organ of a plant shows three distinct stages or phases.

1. *Formative stage:* In this stage, meristematic cells divide and multiply in number.

2. *Stage of enlargement or elongation:* In this stage, the newly formed cells enlarge in size and elongate.

3. *Stage of maturation:* In this stage, the elongated cells get specialised to form various tissues and attain maximum size.

Regions of growth

Corresponding to the three stages, at the tip of a stem or root, three zones of growth are recognised. At the extreme tip is the formative zone or region of cell formation. Just behind this is the zone of elongation or region of cell enlargement. Following this is the zone of specialisation or region of maturation.

These three zones of growth in a root tip can be shown by means of a simple experiment. A germinating bean seed with a root (i.e., radicle) about an inch long is selected. The root is marked from the tip upwards at equidistant intervals with waterproof Indian ink. The seed is pinned to a cork pad with the root pointing downwards. Then it is kept in a moist chamber. After a few days it is seen that the lines at a little distance behind the tip become widely separated whereas lines in the other regions remain more or less the same. This shows that maximum elongation takes place behind the tip. (Fig. 8.1)

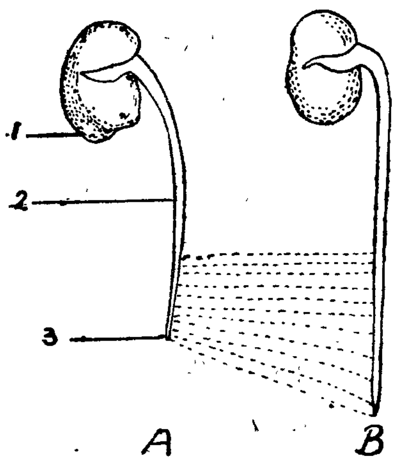


FIG. 8.1

Experiment to show the region of growth.

A. Before experiment.

1. Germinating bean seed. 2. Root.
3. Root tip.

B. After experiment.

Course of growth

Growth of a cell, an organ or a plant does not take place at the same rate even if the external conditions are uniform. To start with, the growth is slow but increases rapidly to a maximum and then decreases slowly. The total period during which these changes take place at the time of growth is called the Grand Period of Growth.

Measurement of growth

The rate of growth can be measured by using an apparatus called a lever auxanometer or arc indicator.

The lever auxanometer consists of a scale in the shape of an arc, fixed to a stand. The scale is attached to a pulley with a long pointer. As the pulley rotates the pointer moves on the scale. A thread is attached to the growing end of a plant and is allowed to pass over the pulley. A small weight is attached to the free end of the thread to keep it in tension. As the plant grows the weight moves the thread down and this moves the pulley. The needle also moves on the scale. The growth of the plant in length is thus magnified on the scale.

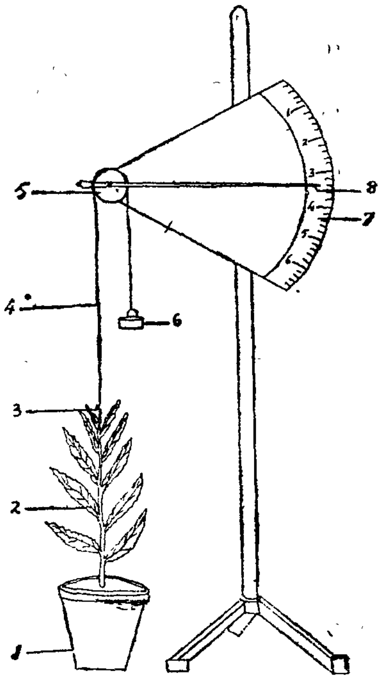


FIG. 8.2 Lever auxanometer
1. Pot 2. Plant 3. Growing point 4. Thread 5. Pulley 6. Weight 7. Scale 8. Pointer

$$\frac{\text{Length of the pointer (for e.g., 20")}}{\text{Radius of the pulley (for e.g., 2")}}$$ gives magnification (i.e. 10).

$$\frac{\text{Number of divisions covered by pointer (for e.g., 4")}}{\text{Magnification}} = \frac{4}{10} \text{ or } .4"$$

is the actual growth. (Fig. 8.2)

Factors affecting growth and development

Growth is influenced by a large number of external and internal factors.

External factors

1. *Temperature:* Growth is a vital phenomenon. It takes place within certain limits of temperature. The minimum temperature at which growth can go on may be 5°C. The maximum temperature is variable and lies somewhere between 30°C and 40°C. As the temperature increases from the minimum, the rate of growth also increases. If the temperature exceeds the maximum limit, growth stops and at a still higher temperature, the plant dies. Therefore between the minimum and the maximum, there is a particular temperature at which growth is most rapid and satisfactory. It is called the optimum temperature which is usually between 25°C and 30°C.

In many cases, the initial growth rate is higher at a higher temperature (about 35°C) but it soon declines with time. Hence a time factor is said to be operative during growth at higher temperatures. Another striking temperature effect upon growth is the low temperature treatment (or vernalisation) which induces early flowering.

2. *Light:* Light is an important factor influencing growth. Growth is usually retarded by light and is accelerated by feeble light or darkness.

Although light has a retarding effect on growth in the presence of light the plant becomes sturdy and healthy with normal development of the stem and leaves. The plants growing in darkness have elongated but slender stems with elongated internodes and poorly developed pale yellow leaves. Such plants are said to be etiolated and this condition is called etiolation. Though growth takes place in feeble light or in darkness plants cannot grow indefinitely in darkness. Light is necessary for the formation of chlorophyll and manufacture of food materials and without sufficient food, growth cannot take place.

The duration of light has marked effect on the growth of plants particularly during the development of flowers and fruits. The length of the daily period of light is called the photoperiod and the response of the plants to the photoperiod is known as photoperiodism.

3. *Water:* An adequate supply of water is essential for growth. Growth stops when there is not enough water in the soil.

4. *Oxygen.* Oxygen is required for respiration. The energy required for growth is obtained from respiration and therefore supply of free gaseous oxygen is necessary for successful growth.

5. *Gravity:* This chiefly affects direction of growth of plant organs.

6. *Chemical influences.* From culture experiments, it is found that elements like carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur etc., are essential for the normal growth of plants. If any one of them is absent, plants do not grow normally.

7. *Mechanical stimuli or forces:* External mechanical factors like contact, also affect the growth. Mechanical contact with support retards the growth of stem of twining plants on the side of contact.

Internal factors

1. *Food reserves:* Food reserves occur within the plant body and therefore it is considered as internal growth factor. But the synthesis of food material depends upon the various external factors. The rate of growth is proportional to the quantity of stored food reserves.

2. *Carbohydrate-Nitrogen ratio: (C/N ratio):* The ratio between carbohydrate and nitrogen compounds is a major factor which determines whether a plant would show only vegetative growth or becomes reproductive. If only a suitable balance is maintained between available nitrogen and carbohydrate synthesis, both vegetative and reproductive growth are promoted. Deficiency of either the nitrogen or carbohydrate results in the appearance of characteristic and recognisable peculiarities of growth.

3. *Heredity and age:* These are also important internal factors.

4. *Hormones:* Growth of the plant is regulated by certain chemical substances which are synthesised by the plant in very small quantities. These substances are produced in one part of the plant in minute quantities as a result of metabolism and are then transported to other parts where they produce specific effects on growth and development. They are known as plant hormones. They are also known as growth hormones,

growth substances, growth regulators, growth factors and phyto hormones.

Auxins and Gibberellins are the important growth hormones. In the case of plants, the action of hormones or auxins was first demonstrated on the coleoptile of Oat (*Avena sativa*) by Boysen-Jenson, Stark and more elaborately by F. W. Went and Thimann. During the germination of Oat,

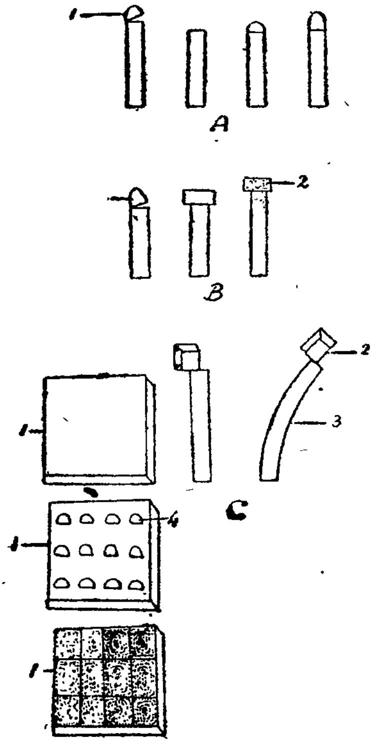


FIG. 8.3

Experiment on oat seedlings.

A. Removal and replacement of coleoptile tip.

1. Coleoptile tip.

B. 1. Coleoptile tip.
2. Agar block containing hormone.

C. 1. Agar
2. Agar block
3. Curvature
4. Coleoptile tip.

(and other grass) seeds, a cylindrical structure with a conical top enclosing the plumule grows above the ground level. This structure is known as the coleoptile. It has been observed that when the tip of the coleoptile is cut off, growth is retarded. But when the tip is replaced, growth is resumed almost at the normal rate. Evidently the tip produces something which when transmitted down the coleoptile induces growth. That something is now known to be auxin.

In another experiment, the tip of the coleoptile is cut off and is placed on a thin layer of agar (3%) for about an hour. The agar is then cut into small blocks and if one such block is placed on the cut surface of the coleoptile, growth continues. The shows that the auxin produced by the tip of the coleoptile is transmitted to the agar block and from there into the decapitated coleoptile. Further it is noted that if the agar block is placed on one side of the decapitated coleoptile, growth is more rapid on this side resulting in a curvature of the coleoptile. Thus the auxin accelerates the growth of this side. (Fig. 8.3)

It is thus clear that growth hormones are transported in the plant in the downward direction i.e., from the tip to the elongating region. However, upward conduction also takes place by transpiration.

Chemical nature of auxins

Kogl and his workers extracted from human urine, three substances capable of promoting growth of plants. They are auxin *a*, auxin *b* and hetero auxin.

Auxin *a* is auxentriolic acid ($C_{18}H_{32}O_5$) and is found in Yeast, Aspergillus and Grasses.

Auxin *b* is auxenolinic acid ($C_{18}H_{30}O_4$) and is found in vegetable oils and Rhizopus.

Heteroauxin is Indole-3-acetic acid ($C_{10}H_9O_2$) and is found in maize, yeast etc. It can also be synthesised in the laboratory.

Hormones are initially present in plant tissues in the form of their precursors. The precursors are converted into active hormones by enzyme action. e.g., Aminoacid tryptophan is the precursor of heteroauxin.

Besides the three natural auxins mentioned above, a number of synthetic substances possessing the properties of auxins have been discovered. They are (1) Phenyl acetic acid, (2) α naphthalene acetic acid, (3) Indole butyric acid,(4)2-4-Dichloro-phenoxy acetic acid (2-4-D) and (5) 2-4-5 Trichloro-phenoxy acetic acid (2-4-5T).

Practical applications of Auxins

Auxins are used in a number of ways, both, in agriculture and horticulture.

1. Auxins are responsible for initiating as well as promoting cell division and cell elongation.
2. Auxins initiate the formation of roots in cuttings.
3. Auxins prolong dormancy; induce fruiting and prevent fruit dropping.
4. Auxins are responsible for the germination of seeds and for the growth of plant organs.
5. Some chemicals bring about the shortening of the internodes.
6. Some prevent lodging of plants (i.e., falling down of plants due to an excessive elongation and softening of cells in the basal internodes) and cause them to grow stiff, woody and erect.
7. Auxins are sometimes responsible for inhibiting the development of lateral buds.
8. Auxins have the effect of breaking the dormancy of bulbs, tubers etc.
9. Auxins generally delay or inhibit flower production but in some cases promote flowering.
10. Auxins produce parthenocarpic fruits or seedless fruits.
11. Certain synthetic substances like 2-4-D (Dichlorophenoxy acetic acid) and 2-2-D (2-2-Dichloro propionic acid) are used in the eradication of weeds.
12. Auxins play an important role in the movement of plant organs in response to light, gravity etc.

Recently another important growth hormone called Gibberellin has been discovered. It brings about a rapid and excessive elongation of the stem. In Japan, the farmers noticed that certain diseased rice plants grew abnormally thin and tall. They called the disease as 'Bakanae or foolish seedling disease.' It is then found that the disease is due to the infection of a fungus called *Gibberella fujikuroi*. In 1938, Japanese scientists isolated two active principles from this fungus and called them Gibberellin *A* and Gibberellin *B*. Later British

and American scientists obtained another compound from the cultures of this fungus and called it Gibberellic acid. The commercial gibberellin is a mixture of all the three chemicals named above.

(*a*) Gibberellins induce the formation of seedless fruits.
(*b*) They remove dwarfism; stimulate elongation of internodes and accelerate flowering.
(*c*) They stimulate seed germination.
(*d*) Gibberellins are used for breaking dormancy of tubers and seeds.
(*e*) They are also used for the increase in size. and yield of fruits like grapes, oranges etc.

5. *Vitamins:* Vitamins are organic substances which are synthesised by plants and play an important role in the growth and development. For example, vitamin A plays a role in photoperiodism Vitamin B_1 (Thiamine) and Vitamin B_3 (Nicotinic acid) are essential for normal root development in green plants. Vitamin B_2 (Riboflavin) involves in some metabolic activites. Vitamin C (Ascorbic acid) acts as a catalyst in photosynthetic phosphorylation. Vitamin K is a regulator of oxidation-reduction processes in living cells and acts as a catalyst in the cyclic electron transport during photosynthesis.

MOVEMENTS

Plant movements are broadly classified into two categories (1) movements of locomotion and (2) movements of curvature. When the plant or the plant parts move bodily from one place to another, it is called movement of locomotion. e.g., Chlamydomonas. When the plant parts move usually in the form of curvature, it is called movement of curvature. e.g., movements of stem tip, root tip etc.

Movements in plants are influenced by certain external and internal factors. The factors which induce the movements are called stimuli and the reaction of the plant to the stimulus is called the response. The irritability or sensitiveness i.e., response of a plant to stimulus is an important property of protoplasm.

Movements whether locomotory or curvature may be either spontaneous or induced. The movements which take place

spontaneously i.e., without the effect of external stimuli like light, gravity etc., are termed spontaneous or autonomic movements. The movements which are caused by external stimuli are called induced or paratonic movements. The paratonic movements are usually of three types namely tactic movements, tropic movements and nastic movements.

Classification of Plant Movements

- Movements
  - Movements of locomotion
    - Autonomic
    - Paratonic
      - *Tactic*
        1. Phototactic
        2. Chemotactic
        3. Thermotactic
        4. Aerotactic
  - Movements of Curvature
    - Autonomic
    - Paratonic
      - *Tropic*
        1. Phototropic
        2. Geotropic
        3. Hydrotropic
        4. Chemotropic
        5. Thigmotropic
      - *Nastic*
        1. Photonasty
        2. Chemonasty
        3. Thermonasty
        4. Nyctinasty
        5. Seismonasty

Tactic movements

Tactic movements are movements of locomotion which are induced by external stimuli. The common tactic movements are:

1. *Phototactic movements:* Phototactic movement is the movement of an organism in response to the stimulus of light. For example, Algae move towards the source of light when the light is weak but when light is strong, they move away from the light.

2. *Chemotactic movements:* The movement of an organism in response to the stimulus of chemical substances is known as the chemotactic movement. e.g., The antherozoids of plants like bryophytes move towards the archegonia due to the attraction of certain chemical substances like malic acid secreted by the archegonia.

3. *Thermotactic movements:* Thermotactic movement is the movement of an organism in response to the stimulus of heat. If a vessel containing water with chlamydomonas is warmed on one side, the algae move towards the warm side in response to heat. But when the water becomes hotter on that side, they move away from that side.

4. *Aerotactic movements:* This is the movement of an organism in response to the stimulus of air. e.g., Bacteria move to places where the oxygen concentration is high.

Tropic movements or Tropisms

Tropic movements are induced movements in which the direction of movement is determined by the direction of the stimulus. Depending upon the nature of the stimulus, the following kinds of tropisms are recognised (1) Phototropism, (2) Geotropism, (3) Hydrotropism, (4) Chemotropism and (5) Thigmotropism.

1. *Phototropism:* The movement of curvature in response to light is called phototropism. It is also known as heliotropism. The stem is positively phototropic because it grows towards the light. The root is negatively phototropic because it grows away from the light. The leaves grow at right angles to the direction of light and therefore they are known as diaphototropic or transversely phototropic.

Phototropism can be demonstrated by keeping a pot plant inside the phototropic chamber (or dark chamber). The chamber consists of a rectangular wooden box, painted black on all sides and is provided with a small opening on one side through which light can pass. After a few days, the stem tip curves and grows towards the opening i.e., the source of light. This experiment proves that the stem is positively phototropic. (Fig. 8.4)

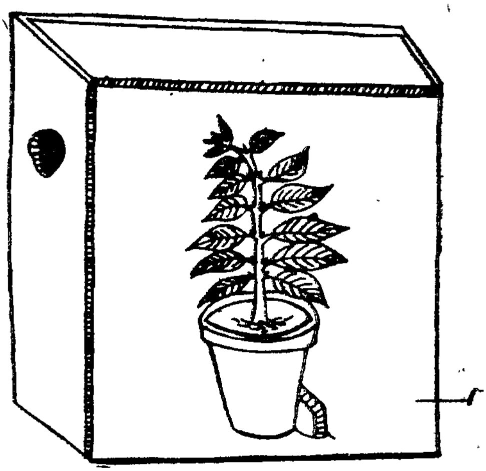


Fig. 8.4 Experiment to demonstrate phototropism
1. Dark chamber box

The mechanism of phototropic curvature is believed to be due to auxins. When a plant is subjected to illumination on one side, the auxins accumulate in the shaded side. As a result of this, the stem bends or curves towards the light.

2. *Geotropism:* Geotropism is the movement of curvature in response to the stimulus of gravity. The root is positively geotropic becuase it grows towards the centre of gravity. The stem is negatively geotropic because it grows against the force of gravity. Lateral roots and branches grow at right angles to the force of gravity and they are called diageotropic or transversely geotropic.

Geotropism can be shown by a simple experiment. A potted plant is kept in a horizontal position. After sometime, the shoot tip bends upwards and becomes vertical. This is due to geotropism.

When a plant is kept horizontally and rotated on its own axis, there is no curvature. This can be demonstrated by an instrument called klinostat. It consists of a rod with a disc

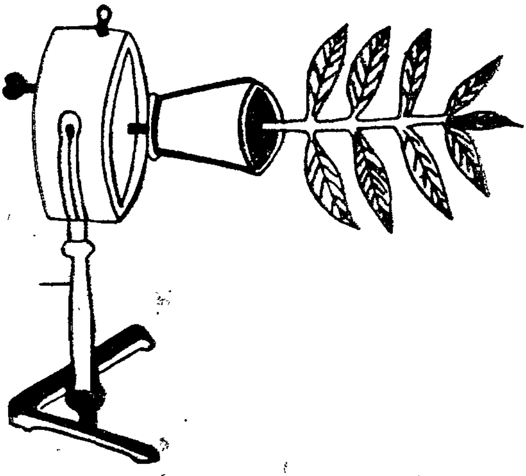


FIG. 8.5 Experiment to demonstrate geotropism
1. Klinostat

attached to one end and a clock work mechanism for rotating the rod and the disc. A small pot plant is attached to the disc and the klinostat is placed in a horizontal position.

The clock is made to work. The plant gets rotated slowly on its axis. It is noticed that the plant continues to grow horizontally without curving because gravity is made to act on all sides of the plant equally. Therefore the effect of

gravity is nullified. If, however, the clock is stopped, the horizontal stem tip curves up. (Fig. 8.5)

Geotropic curvature is caused by the activity of auxins. When the plant is placed horizontally, the auxins accumulate on the lower side. In the case of stem, accumulation of auxins on the lower side accelerates growth and therefore the stem bends upwards. But in the case of root, the excess hormone retards growth and therefore the root bends downward.

3. *Hydrotropism:* The movement of curvature exhibited by roots in response to the stimulus of water or moisture is called hydrotropism. Roots are positively hydrotropic. This can be demonstrated with germinating seeds. These seeds are allowed to grow in a sieve containing moist saw dust. The sieve is then kept in an inclined position. The concentration of water will be greater in the lower half than in the upper. At first the roots grow in a downward direction due to the stimulus of gravity but then they bend and grow along the sieve towards the lower side where there is greater concentration of water. This shows that roots are positively hydrotropic. Moreover, here, hydrotropic stimulus is greater than that of gravity. (Fig. 8.6)

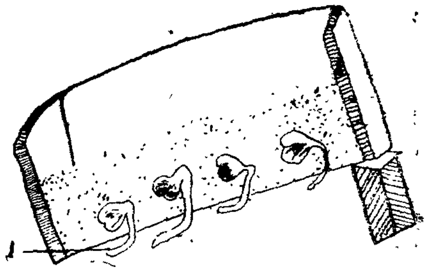


Fig. 8.6

Experiment to demonstrate hydrotropism

1. Root of the seedling

4. *Chemotropism:* The movement of plant organs in response to chemical influences is known as chemotropism. Pollen tube grows through the style towards the micropyle being induced by substance secreted by the stigma.

5. *Thigmotropism:* Thigmotropism is the movement in response to the stimulus of contact. This is seen in the case of tendrils. If the tip of the tendril comes in contact with a support, it exhibits movement.

Nastic Movements

Nastic movements are caused by external stimuli but the direction in which the movement takes place depends upon

internal factors and not on the direction of the stimulus. The stimuli influence the organ with equal intensity from all directions. Usually leaves and petals show nastic movements. Depending upon the nature of the stimulus, the nastic movements are of the following types.

1. *Photonasty:* This is the movement brought about by a change in the intensity of light e.g., Lotus flower opens on illumination and closes on darkness.

2. *Chemonasty:* Chemonasty is the movement induced by chemical substances. If substances like albumin, phosphate etc., is placed in the centre of the leaf of Drosera, the tentacles move towards it.

3. *Thermonasty:* The movement induced by a change in the temperature of the surroundings is called thermonasty. Leaves and flowers open when the temperature is high and close when the temperature is low.

4. *Nyctinasty:* Nyctinasty, also known as sleep movements, is the movement induced by the alternation of day and night. Leaflets of plants belonging to the family Leguminosae exhibit this kind of movement. The leaves of the rain tree fold and hang down during night time; as though in sleep. But they assume their normal shape or position again in the morning.

5. *Seismonasty:* Seismonasty is the movement induced by mechanical stimuli such as contact or touch. This is seen in the sensitive plant, *Mimosa pudica.* In this plant the leaves are bipinnate; the main rachis and the secondary rachii are pulvinate. If a tip of a leaflet is touched, the leaflets nearest to the affected one, first close in pairs and this is followed by the closure of adjacent leaflets in pairs one after another. Evidently a stimulus passes down through the tissues of the leaf causing changes in the turgidity of the cells to result in the alteration of position. The leaf slowly resumes the former position after a few minutes, if it is kept undisturbed. The movement is brought about by variations in the turgidity of the cells on the opposite sides of the pulvinus. But recently it is believed that a hormone moves rapidly downward and produces the changes.

ANNEXURE

ANATOMY — FIGURES

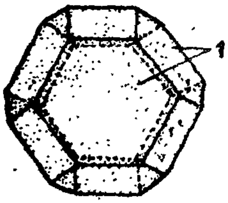


Fig. 2.19
Three dimensional model of a parenchyma cell - Orthic tetrakaidecahedron (diagrammatic)
1. facets

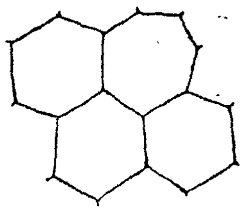


Fig. 2.20
Transection of parenchyma without intercellualar spaces X 134

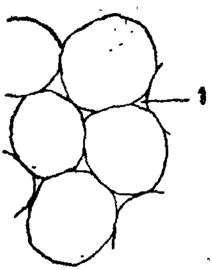


Fig 2,21
Transection of parenchyma cell *with intercellular spaces* X 134
1. *intercellular* space

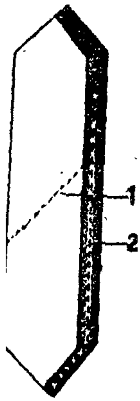


Fig. 2.22
Three dimensional model of a fusiform initial (diagrammatic)

1. *Plane of anticlinal division*
2. Plane of periclinal division

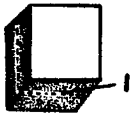


Fig. 2.23
Three dimensional model of a ray initial (diagrammatic)
1. plane of periclinal division

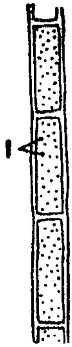


Fig. 2.24
Xylem parenchyma strand (diagrammatic)
1. Simple pits

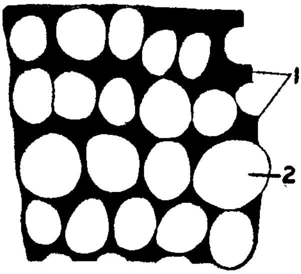


Fig. 2.25
Transection of angular collenchyma X 300 1. thickenings at the corners 2. collenchyma cell

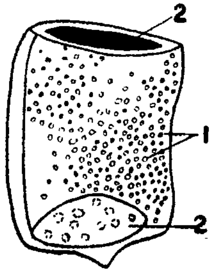


Fig. 2.26
Simple porous vessel member X 67
1. lateral wall pitting
2. end wall perforation

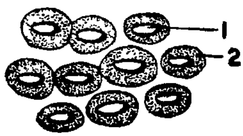
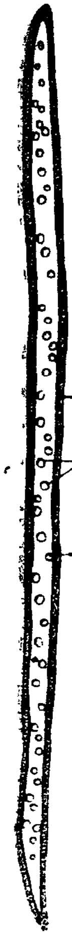


Fig. 2 27
Lateral wall pitting enlarged X 340
1. pit aperture
2. border



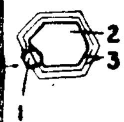


Fig.
2.29

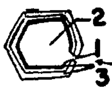


Fig.
2.31

Fig. 2.28.
Tracheid (diagrammatic

1. bordered pits
2. secondary wall

Fig, 2.29
Transection of a tracheid (diagrammatic)

1. bordered pit
2. lumen
3. secondary wall layers

Fig. 2.30
Fiber X 67

1. Reduced bordered pits
2. Secondary wall

Fig. 2.31
Transection of fiber (diagrammatic)

1. pit aperture
2. lumen
3. secondary wall layers

Fig. 2.32
Longitudinal section **of collenchyma X 340**

1. **thickening at the corner**

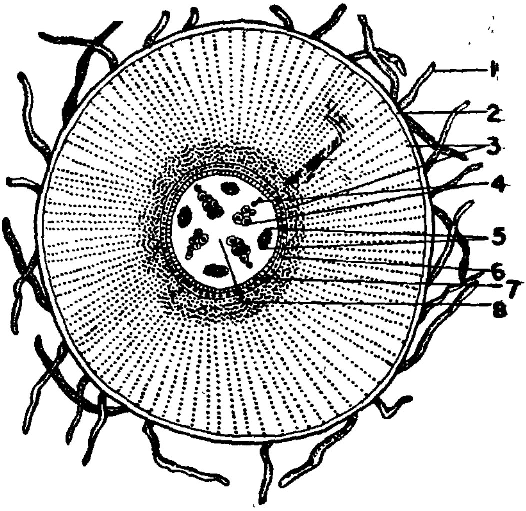


Fig. 2.33
Transection of young dicot root of Ricinus communis X 53
1. root hair 2. rhizodermis 3. cortex 4. primary xylem
5. primary phloem 6. endodermis 7. pericycle 8. pith

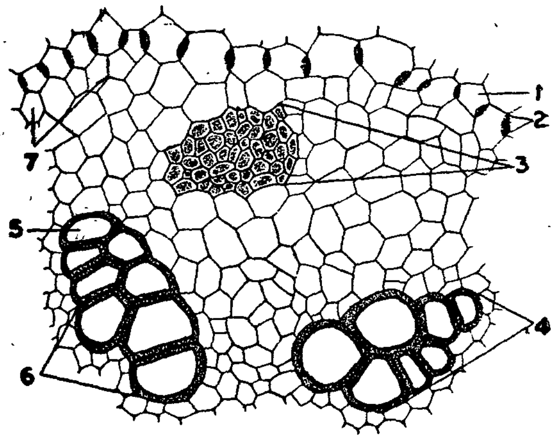


Fig. 2.34
Transection of a portion of young root of Ricinus communis (cortex ommitted) X 90 1. endodermis 2. casparian thickening 3. primary phloem 4. primary xylem 5. protoxylem element 6. metaxylem element 7. pericycle

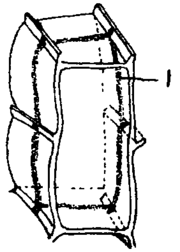


Fig. 2.35
Three dimensional model of an endodermal cell (diagrammatic)

1. casparian thickening band

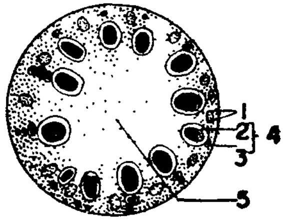


Fig 2.36
Transection of stele of a monocot root (diagrammatic)

1. primary phloem
2. metaxylem element
3. protoxylem element
4. primary xylem
5. pith

Fig 2.37—2.40 Diagrammatic representation explaining the mechanism of secondary growth

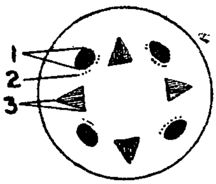


Fig. 2.37
Differentiation of vascular cambium internal to primary phloem

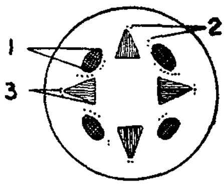


Fig. 2.38
As in Fig. 2.37 together with differentiation of vascular cambium opposite to primary xylem

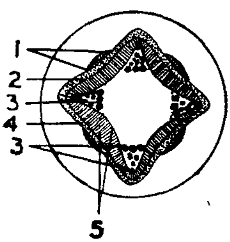


Fig. 2.39
Continuity of vascular cambium established in a lobed manner and the development of secondary phloem and secondary xylem

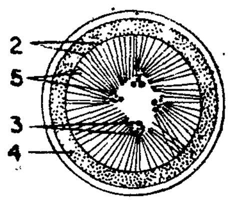


Fig. 2.40
Formation of vascular cambium in the form of a ring

1. primary phloem
2. vascular cambium
3. primary xylem
4. secondary phloem
5. secondary xylem

Fig. 2.41 — 2.42 Ricinus communis

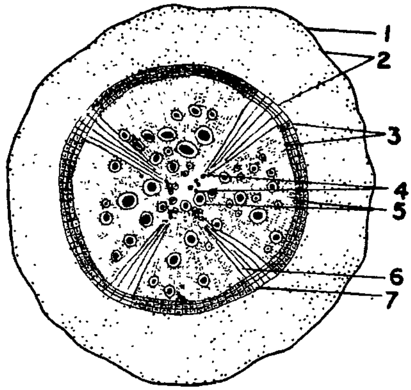


Fig. 2.41 Transection of old root X 54

1. Epidermis 2. Cortex 3. Secondary phloem 4. Primary xylem
5. Secondary xylem 6. Xylem ray 7. Phloem ray

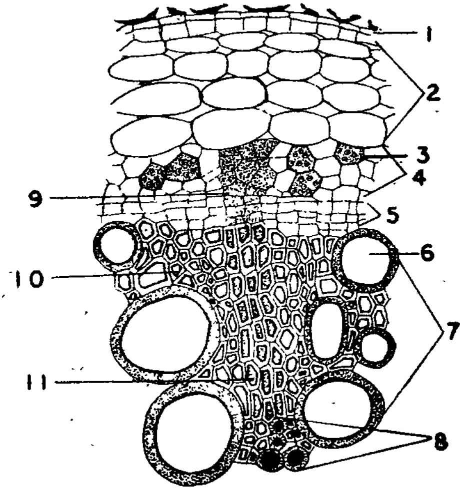


Fig. 2.42 Transection of part of root X 134
1. Epidermis 2. Cortex 3. Sieve tube element
4. Secondary phloetm 5. Cambial zone 6. Vessel
7. Secondary xylem 8. Primary xylem
9. Phloem ray 10. Xylem fiber 11. Xylem ray

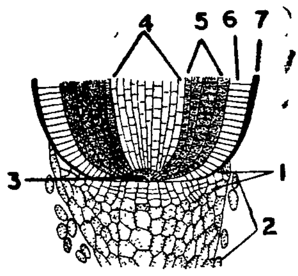


Fig. 2.43
Longitudinalsection of a root apex (diagrammatic)
1. Calyptrogen
2. Root cap
3. Apical meristem
4. Vascular region
5. Cortex
6. Epidermis
7. Mucilaginous layer

Fig. 2.44—2.45 Chloris barbata

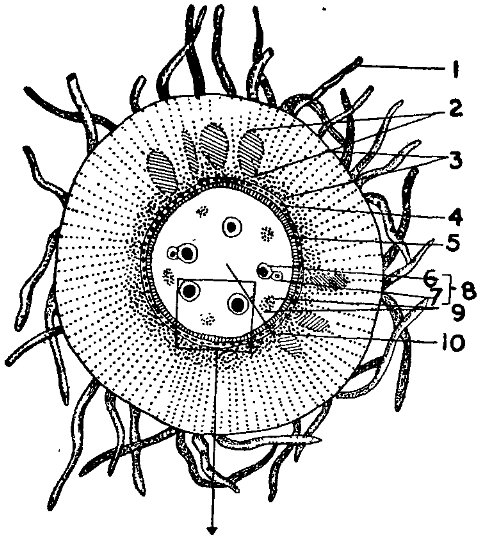


Fig. 2.44
Transection of root X 67
1. Root hair
2. Air-cavity
3. Cortex
4. Endodermis
5. Pericycle
6. Metaxylem element
7. Protoxylem element
8. Primary zylem
9. Primary phloem
10. Pith

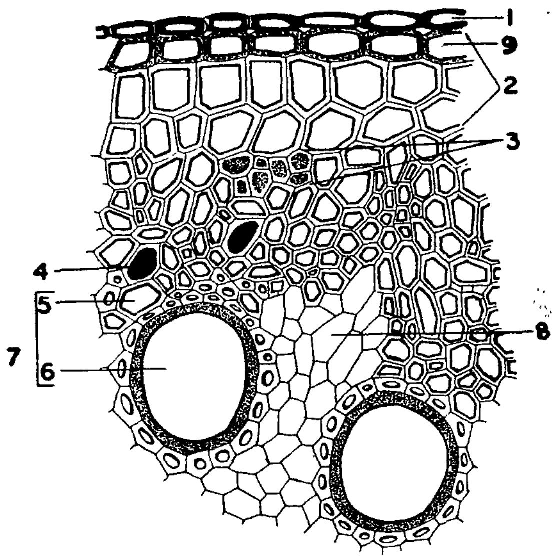


Fig. 2.45 Transection of a portion of root X 134
1. Epidermis 2. Cortex 3. Primary phloem
4. Tannin containing cell 5. Protoxylem element
6. Metaxylem element 7. Primary xylem
8. Ground tissue (Parenchymatous)

Fig. 3.29—3.33 Ricinus communis

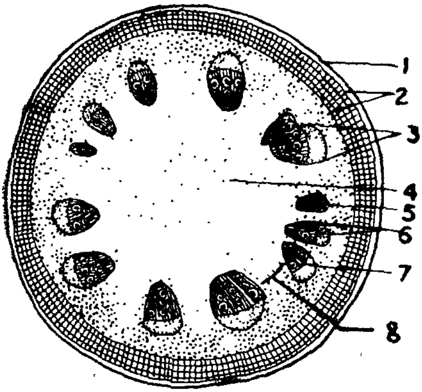


Fig. 3.29

Transection of young stem X 22

1. epidermis 2. cortex 3. vascular bundle 4. pith 5. fascicular cambium 6. primary xylem 7. primary phloem 8. medullary or pith ray

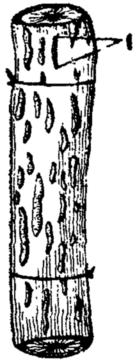


Fig. 3.30

Portion of old stem (diagrammatic)

1. lenticel surface view

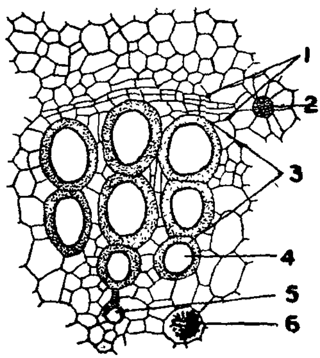


Fig. 3.31

Transection of vascular bundle (cortex, epidermis omitted) X 134

1. *fascicular cambium*
2. secretory cell
3. metaxylem element
4. *protoxylem element*
5. protoxylem lacuna
6. druse

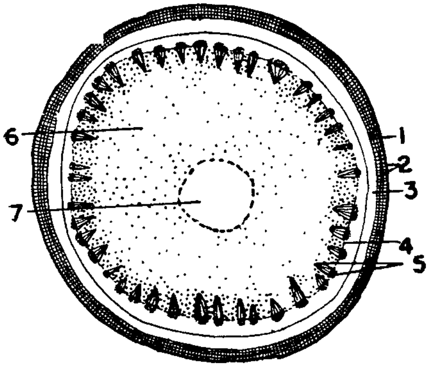


Fig. 3.32
Transection of stem at the commencement of secondary growth, ground-plan X 22
1. epidermis. 2. collenhymatous hypodermis; 3. cortex; 4. cambial ring 5. vascular bundle 6. parenchymatous ground tissue 7. hollow center

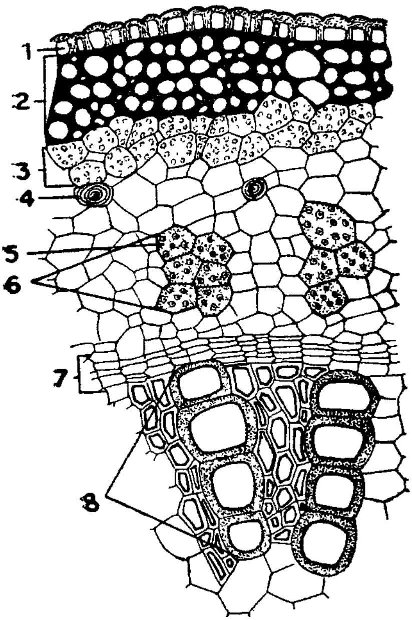


Fig 3.33
Transection of one sector of stem at the commencement of secondary growth as shown in Fig. 3.32 X 134
1. epidermis
2. collenchymatous hypodermis
3. chlorenchymatous cortex
4. sclereid
5. sieve tube elemenet
6. primary phloem
7. cambial ring zone (broken)
8. primary xylem

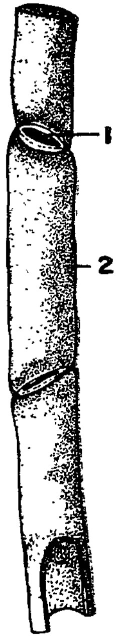


Fig. 3.34
Vessel (diagrammatic)
1. end wall perforation
2. vessel member (lower end cut open to show the lumen)

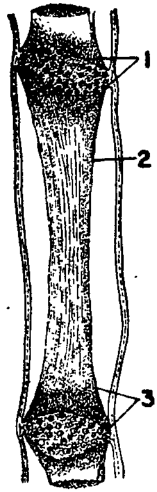


Fig. 3.35
Sieve tube element at the functioning stage X 134
1. sieve plate (tilted)
2. slime
3. slime plug

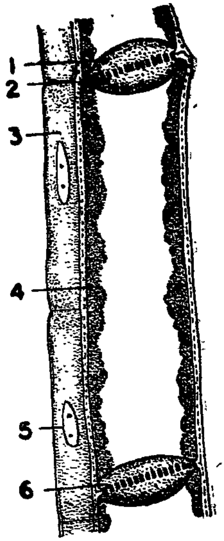


Fig. 3.36
Longitudinal section o sieve tube element at non-functioning stage X 134
1'. callose
2. sieve plate
3. companion cell
4. cytopliasm.
5. nucleus
6. sieve pore

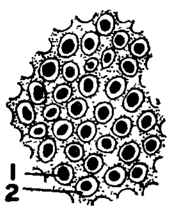


Fig. 3.37
Surface view of a portion of sieve plate (diagrammatic)
1, sieve pore 2. callose cylinder

Fig. 3.38—3.39 Chloris barbata

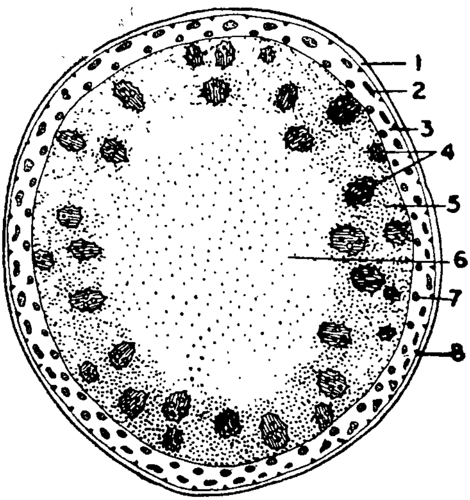


Fig. 3.38 Transection of culm - ground plan X 54

1. epidermis
2. chlorenchyma
3. eortex (sclerenchymatous)
4. vascu'ar bundle
5. sclerenchymatous ground tissue
6. parenchymatous ground tissue
7. sma'l vascular bundle
8. sclerenchyma strands

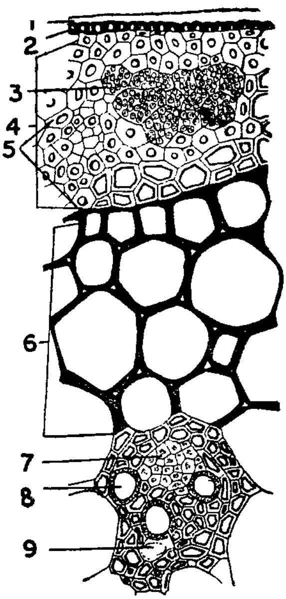


Fig. 3.39

Transection of part of culm as shown in fig. 3.38 X 134

1. cuticle
2. epidermis
3. chlorenchyma
4. selerenchymatous cortex
5. small vascular bund'e
6. selerenchymatous ground tissue
7. primary phloem
8. metaxylem element
9. protoxylem lacuna

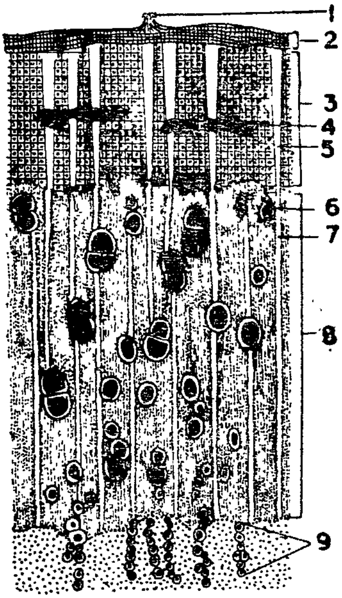


Fig. 3.40
Diagrammatic transection of very old stem of **Ricinus communis** showing the distribution of vessels, rays etc

1. lenticel
2. periderm
3. secondary phloem
4. nests of selereids
5. phloem ray
6. vessel
7. xylem ray
8. secondary xylem
9. primary xylem

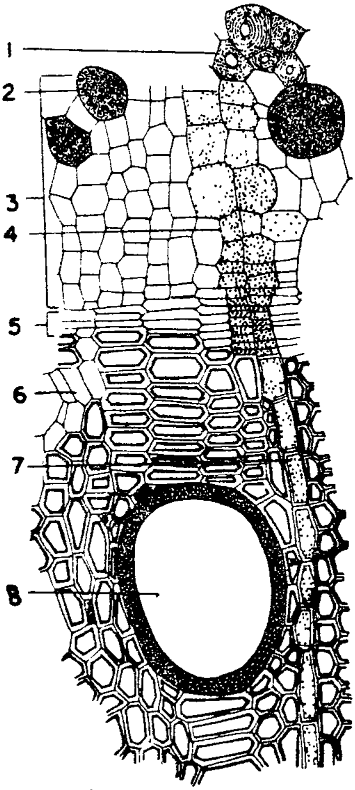


Fig. 3 41

Transection of a portion of secondary phloem near the cambial zone as indicated in Fig. 3.40 X 137

1. nests of selereids
2. sieve tube element indicated by sieve p'ate
3. secondary phloem
4. phloem ray
5. cambial zone
6. xylem parenchyma
7. xylem ray
8. vessel

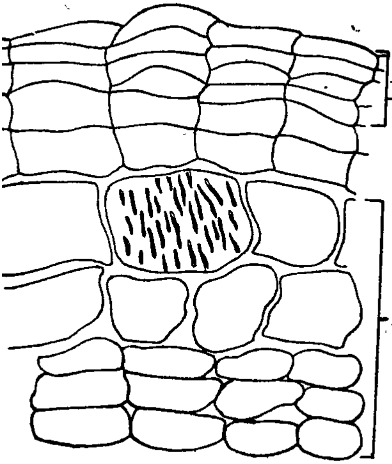


Fig. 3.42
Transection of phellogen and phelloderm
X 134

1. phellogen
2. phelloderm

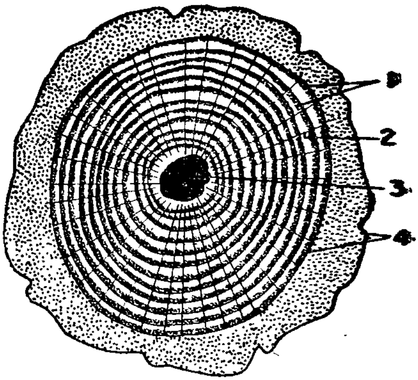


Fig. 3.45 Transection of a tree trunk (disc) to show the sap wood with growth rings and heart wood (diagrammatic)

1. single growth ring
2. xylem ray
8. heart wood
4. bark

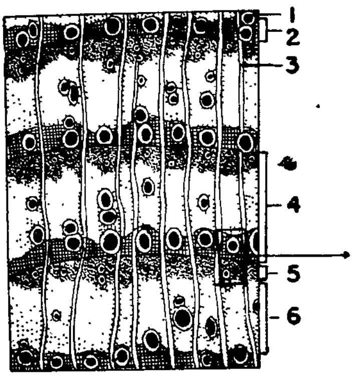


Fig. 3.43
Transection of secondary xylem (wood), showing growth rings X 53

1. vessel
2. xylem parenchyma
3. xylem ray
4. single growth ring
5. summer or late wood
6. spring or early wood

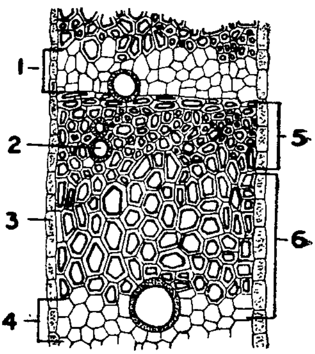


Fig. 3.44
Transection of a part of a growth ring as indicated in Fig. 3. 43 (diagrammatic)

1. xylem parenchyma
2. vessel
3. xylem ray
4. xylem parenchyma
5. summer or late wood
6. spring or early wood

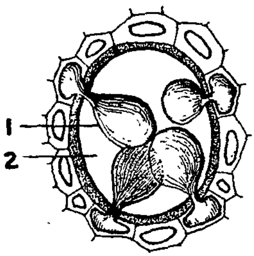


Fig. 3.46

Transection of a vessel member *showing tyloses* X 125

1. tylose 2. vessel lumen

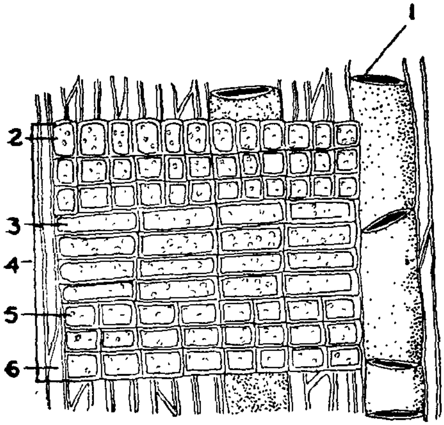


Fig. 3,47

Radial longitudinal section of secondary xylem showing the horizontal and vertical system of the tissues X 125

1. **vessel**
2. **upright** cell of the ray
3. **procumbent** cell of the ray (both 2 & 3 represent the hirozontal system)
4. ray
5. pit.
6. xylem fibers (1 & 6 represent the vertical system)

Fig. 3.87—3.94 **Ricinus communis**

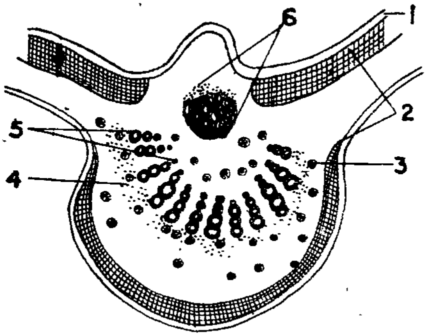


Fig 3.87

Transection of midrib X 54

1. Adaxial epidermis 2. Hypodermal collenchyma 3. Druse 4. Primary phloem 5. Primary xylem 6. Adaxial vascular bundle

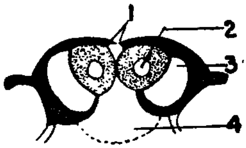


Fig. 3.88

Transverse section of stoma X 550

1. Outer ledge
2. Guard cell
3. Subsidiary cell
4. Substomatal chamber

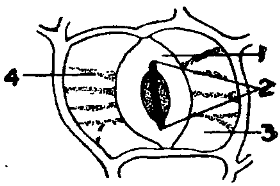


Fig. 3.89

Surface view of stoma X 550

1. Guard cell
2. Stomatal pore
3. Subsidiary cell
4. Cuticular thickening

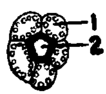


Fig. 3.90

Transection of veinlet X 550

1. Border chlorenchyma 2. Tracheid

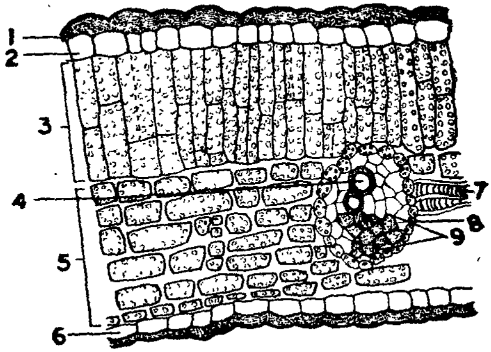


Fig. 3.91

Transection of lamina X 215

1. Cuticle 2. & 6 Adaxial and abaxial epidermis
3. Palisade tissue 4. Primary xylem 5. Spongy mesophyll
7 Longitudinal sectional view of a part of primary xylem element
8. Border parenchyma 9. Primary phloem

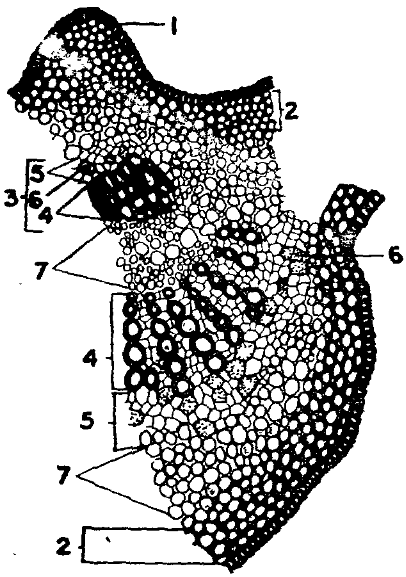


Fig. 3.92

Transection of midrib in part X 35

1 Adaxial epidermis 2. Hypodermal collenchyma
3. Adaxial vascular bundle 4. Primary xylem 5. Primary phloem
6. Sieve tube element 7. Ground parenchyma

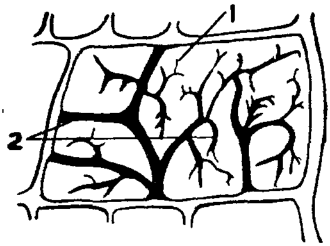


Fig. 3.93
Surface view of areole
(cleared lamina) X 75
1. Veinlet
2. Veins

Fig. 3.94
Longitudinal section of palisade tissue (diagrammatic)
1. Intercellular spaces
2. Palisade cells

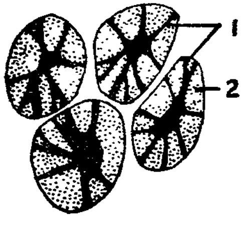


Fig. 8.7
Fruit of Pyrus communis
Transection X 184
1. simple and ramiform pits
2. secondary wall layers

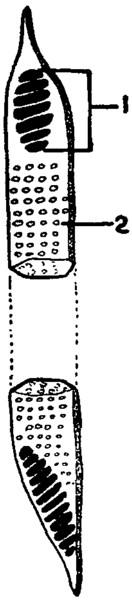


Fig. 8.8
Scalariform porus ves el member (diagrammatic)
1. scalariform end wall perforation plate
2. lateral wall pitting

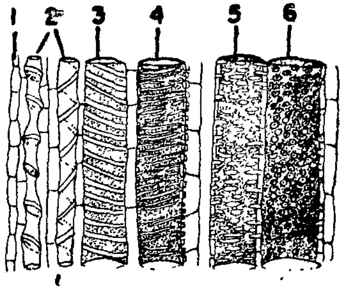


Fig. 8.9

Young internode of Ricinus communis—Longitudinal section (diagrammatic)

1. paranchyma
2. annular and stretched annular protoxylem elements
3. helical elements of protozylem
4. scalariform elements of protoxylem
5. reticulate elements of metaxylem
6. pitted elements of metaxylem (all shown only in parts)

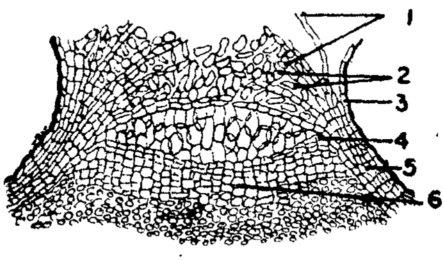


Fig. 8.10

Transection of lenticel of Ricinus communis (diagrammatic)

1. closing layers
2. complementary or filling cells
3. epidermis
4. phellogen
5. phellem
6. phelloderm

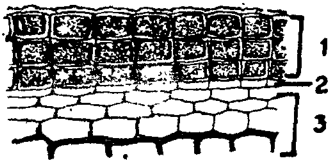


Fig. 8.11
Transection of phellem (diagrammatic)
1. phellem
2. phellogen
3. phelloderm

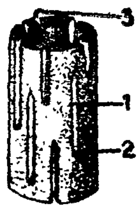


Fig. 8.12
Three dimensional block diagram of vascular cylinder showing its dissection into leaf gap and traces
1. leaf gap
2. vascular bundle
3. inter fascicular area